Production Inefficiency in Fed Cattle Marketing and the Value of Sorting Pens into Alternative Marketing Groups Using Ultrasound Technology

Stephen R. Koontz, Dana L. Hoag, John R. Brethour, and Jodine Walker

The cattle industry batch markets animals in pens. Because of this, animals within any one pen can be both underfed and overfed. Thus, there is a production inefficiency associated with batch marketing. We simulate the value of sorting animals through weight and ultrasound measurements from original pens into smaller alternative marketing groups. Sorting exploits the production inefficiency and enables cattle feeding enterprises to avoid meat quality discounts, capture premiums, more efficiently use feed resources, and increase returns. The value of sorting is between $15 and $25 per head, with declining marginal returns as the number of sort groups increases.

Key Words: cattle feeding, production efficiency, simulation, sorting, value-based marketing, ultrasound

JEL Classifications: C15, D21, D23, Q12

Cattle industry members often discuss the need to improve the quality and consistency of beef products (National Cattlemen's Beef Association [NCBA]; Purcell 2000; Smith et al. 1995). The research reported herein contributes to this discussion by measuring the economic value to cattle feeding enterprises of sorting animals within pens well prior to marketing. The sorting technology fits within

commercial animal handling and marketing systems and is objective in that it relies on weight measurements and ultrasound technology. This research examines the inefficiency that is present in the current production system because of an institutional constraint within the marketing system. The constraint of selling animals within a pen all at one time is an important issue, the impacts of which have not been measured.

The decline in beef demand has been much discussed by beef industry leadership, industry groups, and the popular farm press since the 1980s (see Purcell 1998). Suggested solutions have included the need to improve quality and consistency of beef products (NCBA; Smith et al. 1995). An interest in retained ownership programs and value-added and value-based marketing was prompted in the mid-1990s by

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a need to address demand issues as well as profitability problems that the beef industry faced (Cattle Fax). Grid pricing systems are discussion points within value-based marketing systems (Cross and Savell; Doherty et al.; Fausti, Feuz, and Wagner).

The main premise motivating the work here is that improving meat quality and beef industry profitability likely requires changing of the product form. Similarly, adding value requires that industry participants do something specific or different that warrants rewarding the additional service. This research examines the potential action of sorting animals within pens and changing the resulting composition of animals marketed. No research has examined the value of sorting as we, and the cattle feeding industry, define it.

Literature Review and Research Contribution

The literature on beef industry grid pricing has grown since being identified as a researchable problem (see Schroeder et al.). Published research addresses a variety of economic issues. Primarily, it has examined market opportunities for and risks to producers that use alternative pricing methods. The research is presented as identifying the optimal pricing method for the producer. What is the best method to sell: live weight, carcass weight, or on the grid? The research also usually offers conclusions about pricing efficiency and the ability of market signals to move from the level of the marketing system where meat characteristics are valued to levels where production decisions are made. The main focus of past research has been on price and revenue variability associated with the different pricing methods (Feuz; Johnson and Ward 2005, 2006; MacDonald and Schroeder; Schroeder and Graff). Depending on the sample period, live weight, dressed weight, and grid pricing can all have the highest returns. But the variability is consistently greatest for grid pricing and lowest for live weight. Value-based pricing such as grid pricing and to a lesser extent dressed weight pricing increases risk to the producer but also increases the transmission of price signals upstream.

Value-based pricing methods, grid and dressed, appear to have relatively small impacts on average returns. This has led researchers to suggest that grids need larger premiums and discounts to achieve improved meat quality and to address demand concerns (Fausti, Feuz, and Wagner; Fausti and Qasmi; Johnson and Ward 2006). However, the interesting issue appears to be in the tails of the distribution (Johnson and Ward 2006). Value-based pricing has a large negative impact on the value of poor quality cattle and a small positive impact on good quality cattle. Good quality cattle subsidize poor quality cattle in non–value-based pricing systems such as live weight pricing, and much research finds this (Schroeder and Graff).

There is other interesting research along this grid pricing theme that examines more information on the animals than just carcass characteristics. Lusk et al. use ultrasound data from the time animals are placed on feed to determine optimal pricing method choice for the producer. Walburger and Crews use animal parentage and ultrasound information, which is conducted four times over the animal's life. DeVuyst et al. use animal genotyping and ultrasound information, which is conducted four times while the animal is in the feed yard. The additional information improves pricing method choice and returns to the producer. In this way, the additional information is used to exploit pricing inefficiency. However, the last two studies had no ultrasound measurements of marbling and the first two provided no information on the grouping of animals in pens or on how the decision was made to market the animals. Without information on marbling, ultrasound can provide little help marketing an animal at an optimal United States Department of Agriculture (USDA) quality grade. Without information on the grouping of animals, it may be that each animal was sold individually, and this would reduce the production inefficiency that is observed in the commercial practice of batch marketing.

However, the main shortcoming of grid pricing research is that it has not examined changing production practices that change the product form. Past research had the objective of evaluating optimal pricing method choices, but it is unlikely that a simple change in marketing practices will change returns to producers over the long run. Such an opportunity would imply the existence of persistent pricing inefficiencies that are exploited by one side of the transaction—the cattle feeding enterprise. It is likely that if one pricing method is more profitable to producers than other methods, where the product is not different, then price differentials will equilibrate because of the arbitrage. Fausti and Qasmi have shown that premiums and discounts have changed over time, changing the incentives for producers. These changes are not necessarily due to arbitrage but make the point that relative prices change. The lack of change in product form is a limitation of existing research and provides an opportunity for further exploration.[1]

There is research in the animal science literature that illustrates the production inefficiency in the batch marketing of pens of fed cattle. Boleman et al. and McKenna et al. report on the 1995 and 2000 National Beef Quality Audits. Throughout the year of each audit, data were collected from over 25 commercial beef processing facilities for approximately 40,000 animals and 10,000 carcasses, which are representative samples of commercial pen-level transactions. The audits reveal that carcass weights have increased, but the distributions of other quality measures were relatively unchanged. Of the carcasses, 5% to 6% were too light or too heavy to the extent that the carcasses would have been discounted. An additional 4% to 7% of the carcasses had minimal marbling and would have received a discount for grading USDA quality grade standard or lower. Moreover, 8% to 12% of the carcasses had excessive backfat and would have received a discount for grading USDA yield grade 4 or 5. The main conclusions of the audits were that "out" carcasses are persistent and that approximately 15% of animals are overfed and 10% are underfed to the point of being discounted in the pricing system. Overfed and underfed percentages are higher when animal performance and opportunity costs are considered. Animal scientists regularly state that 25% of animals are overfed and 25% are underfed (Brethour 2000, p. 2055).

It is interesting to contrast the animal characteristics discovered in industry audits to the animal characteristics from grid pricing studies. Research by Johnson and Ward (2005, 2006) using large data sets for Iowa, Nebraska, Kansas, and Oklahoma finds comparable carcass quality distributions. The same conclusion is drawn for other studies with relatively large samples of pen-level transactions. However, the studies with small groups of animals have samples that are not representative of animals in a commercial setting. Within the ultrasound literature, there is also considerable variation in the management of the studied animal groups. For some groups, the pen-level variation in quality is not managed, and for others it is closely managed. We take the approach of measuring it.

The research reported herein addresses a gap in the literature. The literature that discusses the concepts associated with value-based marketing has long recognized that production practices must change to address quality and demand problems (Cross and Savell; Fausti, Feuz, and Wagner). However, the grid pricing literature does not allow for changes in production practices or animal characteristics. All past research holds the animal characteristics constant and changes pricing methods. We hold the pricing method constant and change the animal characteristics.

This research estimates through simulation the value of sorting fed cattle well prior to marketing. The sorting regime is based on

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[1] There is a unique body of research within the grid pricing literature that has looked specifically at the economic problem that may generate persistent price differences across the pricing methods. Feuz, Fausti, and Wagner (1993, 1995) and Fausti and Feuz have provided evidence that price differentials across pricing methods may persist due to asymmetric information and different risk preferences of buyer and sellers. The research herein does not address this issue.

weight measurements and ultrasound technology. Thus, this is the production practice change or additional service. The specific management change is that the cattle feeding enterprise weighs and ultrasounds cattle at approximately 80 days prior to slaughter, which is the feeding stage where cattle receive a final growth implant and are handled. The animal has also had time on a high-energy ration, and its genetic potential to respond to feed is being expressed. Based on measurements, cattle can be sorted into groups that are marketed to optimize returns to weight, USDA yield grade, and USDA quality grade relative to feeding costs for each group.

Animal Growth and Development in the Simulation Methods

The general method used is to simulate the results of sorting technology employed by a cattle feeding enterprise. The sorting technology moves fed cattle based on a marginal cost and marginal return evaluation from heterogeneous groups to more homogenous subset groups that are more profitable.

The simulation makes use of the decision support system within ultrasound cattle sorting system (UCSS) technology developed by and reported in Brethour (1989).[2] The main part of the decision support system within the UCSS program is a set of animal growth and carcass development curves or functions. There are three functions that model (1) carcass weight, (2) intramuscular fat deposition (i.e., marbling), and (3) subcutaneous fat deposition (i.e., backfat). In the feed yard, the UCSS uses an ultrasound image of the sagittal plane (shoulder-to-shoulder) over the first and second lumbar vertebrae for each animal. The ultrasound technology measures marbling within the rib eye (longissimus) muscle and measures carcass backfat.[3] Cattle are also weighed at the time of ultrasounding. These measurements and other information are used in growth and development curves to predict (1) slaughter weight, (2) USDA quality grade, and (3) USDA yield grade.

The equation to predict carcass weight T days into the future is a function of the live weight and measurements that estimate of the future dressing percentage at day t. The model is as follows:

$$
\begin{aligned}
CarcassWt&(t + T) \\
&= 0.96 \times (LiveWt(t) + 3.2 \times T) \\
&\quad \times Dressing\%(t + T) + e_1(t + T)
\end{aligned}
\tag{1}
$$

and is discussed in Brethour (1989). This is a standard growth curve. It is assumed animals grow 3.2 pounds per day and there is a 4% marketing shrink. The initial live weight is measured on day t and used by the UCSS to predict a final carcass weight at day $t + T$. The growth curve is used in the simulation to modify carcass weight.

The equation to predict marbling score T days into the future is a function of the ultrasound marbling score at day t and is as follows:

$$
\begin{aligned}
MS(t + T) &= \alpha + \beta\Big\{[(MS(t) - \alpha)/\beta]^{1/\gamma} \\
&\quad + T\Big\}^{\gamma} + e_2(t + T),
\end{aligned}
\tag{2}
$$

where the model is a modified power function and α, β, and γ are parameters with values in the UCSS. This model is reported in Brethour (1991, 1994, 1995, 2000). The initial marbling score is determined by the UCSS through ultrasound and is used to predict a final marbling score T days into the future. The UCSS uses the initial marbling score with other information on the animal to estimate a final marbling score and predict USDA quality grade. The function is used in the simulation to modify USDA

[2] The UCSS is owned by Kansas State University and has been licensed to Cattle Performance Enhancement Company (CPEC) of Oakley, Kansas.

[3] For discussion of ultrasound research and technology see Faulkner et al.; Houghton and Turlington; Perkins, Green, and Hamlin; Smith et al. (1992), and Whittaker et al. For a discussion of instrument grading and ultrasound in value-based marketing see Cross and Whittaker.

quality grade with additional or fewer days on feed.

The equation to predict backfat measurement T days into the future is a function of the ultrasound backfat measurement at day t and is as follows:

$$(3) \quad \begin{aligned} BF(t + T) &= BF(t) \times \exp\{\beta \times T\} \\ &\quad + e_3(t + T) \end{aligned}$$

where β is a parameter with a value in the UCSS. This model is discussed in Brethour (1992, 2000). The initial backfat measurement is determined by the UCSS and is used to predict a final backfat measurement T days into the future. The UCSS uses the initial backfat measurement and other information on the animal to estimate a final backfat measure and predict USDA yield grade. The function is used in the simulation model to modify USDA yield grade with additional or fewer days on feed.

These three equations are standard growth and development models used in animal and meat sciences (see National Research Council).[4] However, there is one important difference. In addition to the predictions, the UCSS makes use of the distribution of the error term associated with each of the models (i.e., $e_j(t + T)$). The simulation uses the UCSS to predict a carcass weight and to calculate probabilities that the carcass will be greater than 950 pounds and less than 550 pounds. Likewise, the simulation predicts a marbling score and calculates the probabilities that the carcass will have higher or lower scores that are consistent with USDA quality grades. Finally, the simulation predicts backfat and calculates the probabilities that the carcass will have scores consistent with USDA yield grades.

The distribution of the error terms from growth and development models are generally not reported and are difficult to find in published research. Their use in the UCSS is a unique value of the tool. The errors from the

models in Equations (1)–(3) are assumed to be normally distributed. The UCSS software calls functions that calculate probabilities from normal cumulative density functions. The mean is zero and is the expected value of the residual from the regression models. Variance is the only other parameter. However, it is not a constant. Variance of the error term increases the further into the future the model is used to predict. The error variance $\sigma_j^2(t + T)$, for model j, is a function of time where T is the number of days past the ultrasound date t. Variance estimates in the UCSS are proprietary and are based on serial slaughter data where the sample is over half a million animals from a 15+ year ultrasound research program. Error variance estimates are available in the UCSS for horizons of 1 to 200 days past ultrasounding. Variances are small for short prediction horizons because animals grow predictably over short time periods once they have been on feed. Variances increase moderately over intermediate time periods and then expand at a more rapidly increasing rate for very long horizons. Nonparametric methods were used to smooth estimates over similar horizons, and estimates are restricted so that longer horizons cannot have smaller variances. Probabilities from the UCSS for an example animal are presented in Table 1. The animal was overfed when it was marketed as part of an unsorted pen at 84 days past ultrasound, and it has high probabilities of being low-choice, yield grade 4 and 5, and weighing more than 950 pounds.

The UCSS is used to calculate expected returns for each animal for 1 to 200 days into the future. The optimal marketing date for the animal is the maximum of expected returns over this 200-day window. Return is based on animal revenue and cost of continued feeding. Revenue is based on price level, expected premium and discounts, and expected animal growth. Cost is based on feed costs, feed consumption, and expected declining performance as animals grow.

The expected return of the ith animal T days past the ultrasound date t is

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[4] See in particular, NRC, *Nutrient Requirements of Beef Cattle, Update 2000*, Chapter 10, "Prediction Equations and Computer Model."

Table 1. Example of Sorting an Overfed Animal That Was Marketed within an Unsorted Pen into Two and Three Alterative Marketing Groups Where the Sort Group Containing That Animal Is Marketed Earlier

| | | | | Example Animal Marketed Within | | | | |
| | | | Unsorted Pen (84 days past reimplant) | | Two Alternative Marketing Groups (70 days past reimplant) | | Three Alternative Marketing Groups (63 days past reimplant) | |
Growth and Development	Grid Categories	Premium/ Discount ($)	UCSS Probability	Expected Value ($)	UCSS Probability	Expected Value ($)	UCSS Probability	Expected Value ($)
Quality grade	Prime	6.00	6.6	0.40	4.0	0.24	0.0	0.00
	Certified	4.00	35.6	1.42	28.2	1.13	15.3	0.61
	Low choice	0.00	39.9	0.00	28.6	0.00	21.8	0.00
	Select	−5.00	17.6	−0.88	38.5	−1.93	53.8	−2.69
	Standard	−12.00	0.3	−0.04	0.7	−0.08	9.1	−1.09
Yield grade	YG1	3.00	0.0	0.00	2.7	0.08	7.9	0.24
	YG2	1.50	0.1	0.00	9.3	0.14	20.4	0.31
	YG3	0.00	9.0	0.00	52.5	0.00	57.0	0.00
	YG4&5	−20.00	90.9	−18.18	35.5	−7.10	14.7	−2.94
Weight	<550	−20.00	0.0	0.00	0.0	0.00	0.0	0.00
	550–950	0.00	7.3	0.00	52.2	0.00	90.1	0.00
	>950	−20.00	92.7	−18.54	47.8	−9.56	9.9	−1.98
Net premium ($/cwt carcass)				−35.81		−17.03		−7.55
Live weight (pounds)			1,565.0		1,520.2		1,453.0	
Carcass weight (pounds)			976.6		948.6		906.7	
Carcass weight change (pounds)			0.0		−28.0		−69.9	
Marginal value of carcass weight change ($/head)			$0.00		−$30.11		−$75.26	
Marginal value of net premium ($/head)			$0.00		$177.71		$256.29	
Marginal value of feed cost change ($/head)			$0.00		$83.87		$129.35	
Net value of sorting ($/head)			$0.00		$231.47		$310.38	

$$E(Return_i(t + T)) = E(Price_i(t + T))$$
$$(4) \qquad\qquad \times\ E(CarcassWt_i(t + T))$$
$$- E(FeedingCosts_i(t + T)),$$

where

$$E(Price_i(t + T)) = Carcass\ Beef\ Price\ Level$$
$$+ \Pr(Prime_i(t + T)) \times PrimePremium$$
$$+ \Pr(Certified_i(t + T)) \times CertifiedPremium$$
$$+ \Pr(Select_i(t + T)) \times SelectDiscount$$
$$+ \Pr(Standard_i(t + T)) \times StandardDiscount$$
$$(5) \qquad + \Pr(YG1_i(t + T)) \times YG1Premium$$
$$+ \Pr(YG2_i(t + T)) \times YG2Premium$$
$$+ \Pr(YG4\&5_i(t + T)) \times YG4\&5Discount$$
$$+ \Pr(Heavy_i(t + T)) \times HeavyDiscount$$
$$+ \Pr(Light_i(t + T)) \times LightDiscount$$

and

$$E(FeedingCosts_i(t + T))$$
$$= FeedPriceLevel$$
$$(6) \qquad \times FeedQuantity_i(t + T)$$
$$\times\ (1 + \Pr(FeedEfficiencyPenalty_i(t + T))).$$

Within the feed yard, the UCSS operator inputs the carcass beef price, premiums and discounts, and the feed price. These prices are held constant in the simulation. It is carcass weight, carcass quality characteristics, feed consumption, and feed efficiency that are changed in the simulation for the individual animal as it is sold at different dates T.

Equation (1) is used in Equation (4) to simulate expected carcass weight. The prediction error variances from Equation (1) are also used to determine the probabilities that a carcass will receive a heavy and a light weight discount in the expected price Equation (5). Equation (2) is used along with its prediction error variance to determine probabilities that the carcass will have different USDA quality grades in Equation (5). Equation (3) is used with its prediction error variance to determine probabilities that the carcass will have different USDA yield grades in Equation (5) and the feed efficiency penalty in Equation (6).

Sorting creates a change in the expected return for each animal. An individual animal may be sold a different number of days past reimplant, e.g., T_m and T_n. Thus, the return to sorting is the difference between the expected return calculations, which is as follows:

$$E(ReturnstoSorting_i(T_m, T_n))$$
$$(7) \quad = E(Return_i(t + T_m)) - E(Return_i(t + T_n)).$$

These expected returns are returns to feeder cattle, initial feeding, and other costs. However, all these costs are the same across different sort horizons so can be ignored in the expected returns to sorting calculation.

The prediction error probabilities help address the issue that individual animals may grow differently from what the models predict. The models generate predictions consistent with typical animals. Through the use of the error distributions, the simulation modifies these expected values to be consistent with individual animals. The resulting expected values incorporate individual animal variation and are consistent with weight and ultrasound measurements at reimplant, measurement errors at reimplant, and nondeterministic growth and development.[5]

The UCSS software measures animal growth and feed performance degradation as feeding continues. The marginal cost of gain is determined through the feed performance assumptions. UCSS assumes 6.5 pounds of feed to a one pound of gain ratio and that animals grow 3.2 pounds per day in live weight or 2.3 pounds per day in carcass weight. The cost of feed was assumed to be $0.075 per pound of feed for the simulation. The feed conversion rate is assumed to decline

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[5] An example can be seen in Table 1. Since the example animal is marketed early, the live weight and carcass weight decrease. Initially, the animal is almost certainly a heavy weight carcass. The expected value is 976.6 pounds. Simulating the marketing of this animal 21 days earlier results in an expected value of 906.7 pounds. However, even 21 days earlier, there remains a 9.9% probability the carcass is heavy weight and this probability results in a discount. The probability is calculated by the UCSS and it captures individual animal deviation from the growth models, which include measurement errors at ultrasound.

once an animal deposits more than 0.6 inches of backfat. The probability that a carcass has 0.6 or greater inches of backfat, from Equation (3), is multiplied by the feed conversion degradation to create the feed efficiency penalty.

The grid price structure used is also presented in Table 1. The base animal within this grid is USDA choice, yield grade 3, and between 550 and 950 pounds. There are premiums for good and discounts for poor USDA yield grade and quality grade carcasses, and there are discounts for out-weight carcasses. The grid is additive and is reasonably typical (see Johnson and Ward 2005, 2006; MacDonald and Schroeder; Ward et al.). The probabilities of the different carcass characteristics are multiplied by premiums and discounts to calculate an expected value of carcass quality. The carcass price was assumed to be $107.88/cwt.

Two example sorts are also presented in Table 1. The example animal is sorted from its original pen into one of two alternative marketing groups and then into one of three alternative groups. The animal that is overfed at 84 days is first marketed 14 days earlier at 70 days and then 21 days earlier at 63 days. As the animal is fed fewer days, the expected value of heavy weight and yield grade 4 and 5 discounts decline. The net premium is negative, increasing from an expected value of −$35.81/cwt to −$17.08/cwt on the entire carcass, so it is a discount. This is the expected value of the marginal value of improved quality. The change in the net premium is multiplied by the weight of the carcass, and its expected value increases $177.71. Marketing the animal earlier results in a carcass with fewer total pounds so there is an expected loss of $30.11 in revenue. The animal also consumes less feed, and there is an expected $83.87 feed cost savings. The expected value of the return to sorting is $231.47. If this animal can be marketed in a group 21 days earlier, then the heavy weight and excess backfat discounts can be further lessened, but the marbling premiums also decline. Sorting improves this animal's expected value $310.38 over the unsorted pen.

Marginal costs of ultrasounding the individual animal are minimal when it is paired with reimplanting. The animals are handled at this time so the additional variable cost is only that of ultrasounding.[6] However, marginal costs of the sorting activity by the cattle feeding enterprise may be substantial. Some sorting systems sort cattle into physically different pens. For example, the Accu-Trac system used by MicroBeef Technologies performs physical sorting and regrouping of animals. Other systems, such as CPEC, identify animals within the same pen through tags. There is considerable flexibility in management of sorted cattle.

Data

The sample of individual animal carcass data and pen composition were from the Gelbvieh Alliance, and animals were slaughtered at ConAgra facilities. Cattle of any breed could be placed in this breed association alliance. Cattle in the alliance were marketed in pen-level transactions, but data used in the simulation were those pens with carcass data collected on individual animals. This is unique. We treat carcass observations as a sample from the population of fed cattle and pen-level transactions as a sample from the population of marketing decisions. Cattle feeding enterprises that were known to sort cattle or use ultrasound were removed from the database.[7] Inclusion would bias downward the value of sorting. The final sample includes 7,173 animals in 100 pens, which contained 40 to 163 animals. The mean is 72 animals. The sample period was more than three years.

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[6] If ultrasounding was performed close to slaughter then prediction errors would be lower but costs would be higher because animals are not handled at this time and animal performance can be impacted by handling. This cost question, as it would pertain to a commercial cattle feeding enterprise, has not been answered by real-time or multiple ultrasound research.

[7] There are cattle feeding enterprises in the sample that, for example, use MicroBeef Technologies. Enterprises that sort were identified through discussions with the alliance.
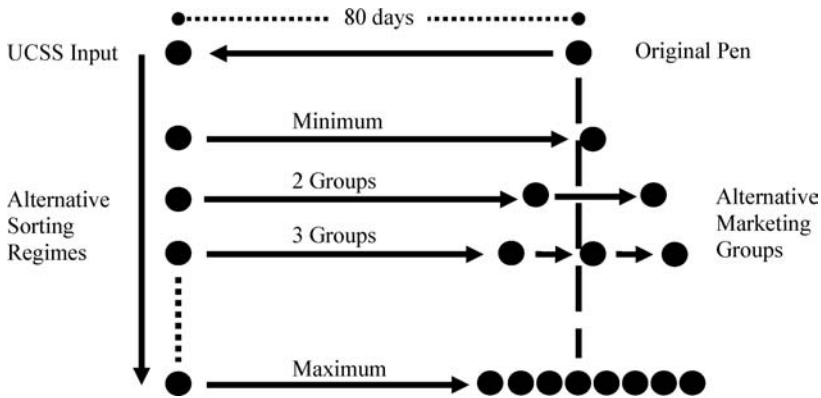
Figure 1. Simulation Model and Sorting Approach

A strength of this study is the sample size, pen structure, and industry representation. Most ultrasound studies have smaller numbers of animals, and many do not consider the pen structure. Lusk et al. analyze 163 animals, and no information is given on pen structure. Walburger and Crews analyzed 674 animals but also provided no information on pen structure. DeVuyst et al. batch marketed 590 animals, but there were only 14 pens.

Comparison of the Gelbvieh Alliance carcass data with the National Beef Quality audit carcass data reveals more high yielding animals, similar distribution of quality grade animals, and similar distribution of out-weight animals. The value of sorting this sample of animals will likely be less than the population of commercial animals.

Sorting Regimes within the Simulation Methods

Carcass data measurements at the time of slaughter are used with the UCSS equations to backcast 80 days. The backcast measurements are then used as initial measurements in the UCSS to calculate the expected profit from 1 to 200 additional days on feed. Animals within each pen may then be sorted into smaller alternative marketing groups. The approach of the simulation is outlined in Figure 1. The backcast creates a sample of animal characteristics approximately 80 days prior to slaughter. This is the left arrow on the top of Figure 1. We then examine a number of different sorting regimes for that pen—following the down arrow to the different regimes.

Maximum return to ultrasound and sorting is determined by marketing every individual animal at the optimal date associated with that animal as predicted by the UCSS:

$$\max_T E(Return_i(t + T))$$

(8)   for each i animals and for $T = 1, \ldots, 200$.

This is the bottom right arrow in Figure 1. The pen structure is not maintained, and this is the simplest simulation. The maximum return also can be viewed as the opportunity cost of batch marketing.

Minimum returns to ultrasounding would be realized by using the technology to find the optimal marketing date for an entire pen structure but not to sort the cattle:

$$\max_T \Sigma_i E(Return_i(t + T)|i \in q)$$

(9)

$$\text{for all } i \text{ animals in pen } q$$

$$\text{and for } T = 1, \ldots, 200.$$

This is shown by the top right arrow in Figure 1. An example is shown where the simulated pen was marketed later. The pen structure was maintained in that the animals were not sold at different dates. Each animal has a series of expected profits estimated by the UCSS over the potential marketing period. The expected profits are totaled for all animals in a pen for each day, and the day with the maximum expected profit for the entire pen is the optimal marketing day for that pen. The

date associated with the maximum of the expected profit for the pen is compared to the backcast horizon of 80 days. The change in the value is the value of ultrasound to the industry without sorting and is defined as the minimal value.

Intermediate returns to ultrasound and sorting can be determined by sorting the pen of animals into a given number of alternative marketing groups where the animals in each group are then all marketed on the date that is optimal for that alternative group:

$$\max_T \Sigma_i E(Return_i(t + T)|i \in r)$$

(10)   for all i animals in group $r \subset q$

and for $T = 1, \ldots, 200$.

This models what the cattle feeding industry considers sorting. Figure 1 illustrates marketing an original pen in two and three alternative groups. If a pen is sorted into two alternative groups, then the animals with the lower half of optimal marketing dates are placed into one group and the animals with the upper half are placed in the second group. Those two groups are marketed at the maximum of the expected profit for each separate group. The same method was used for sorting into a larger number of groups.

A simplifying assumption is needed for structuring the two and greater numbers of alternative marketing groups. These groups are assumed to contain equal proportional numbers of animals to the original pen. The industry that sorts cattle does not create marketing groups with very small numbers of animals. There are 100 pens in the sample, and the number of possible permutations for pen sorts is large. The number of evaluations increases by a power rule with each permutation. The impact of the assumption is that we should underestimate the value of sorting. Nonproportional sorts may be optimal.

Simulation Results

The use of ultrasound to predict optimal marketing dates for entire pens, the minimum economic potential in Figure 1, provided little economic benefit. The average of the most profitable marketing date for pens of cattle was 84 days after reimplant. The standard deviation was 15 days. Given the backcast of 80 days, the actual marketings were on average conducted on a day close to optimal. The results show that on average, cattle feeding enterprises market cattle close to the profit-maximizing date given the institutional constraints of marketing the entire pen at one time and marketing cattle once per week. However, the minimum economic potential needs to be viewed with caution. The base grid prices and feed price are not the actual grid prices or feed prices. The actual grid prices are available in the database, but the feed costs are not. Our base grid is consistent with the average of the actual grid, and the grid prices changed very little over the sample period. Our base feed cost is consistent with average feed costs over the sample period, but it is not possible to determine an optimal date for each pen because of missing actual feed prices. That said, it is still reasonable to conclude that the use of weight and ultrasound measurements would do little to improve profitability within the current batch marketing pen structure. This result is consistent with the literature that examines pricing inefficiency in that ultrasound tends not to be very valuable. The value of ultrasound is in sorting and changing the composition of the pen.

While the most profitable marketing date for pens is on average in 84 days, the average optimal marketing date for individual animals was 108 days past reimplant. This is the maximum economic value scenario in Figure 1. The large difference in days reveals the impact of "out" cattle within a pen on overall pen returns. For the pens within the database, it was economical for the cattle feeding enterprise to sacrifice 24 days of growth on the entire pen to avoid the yield grade 4 and 5 and heavy carcass discounts and feed performance degradation on the relatively small number of animals that are overfed. The difference between the actual and optimal individual marketing dates reveals a large inefficiency in the current production system due to batch marketing and the composition of animals within pens. This inefficiency has

Table 2. Actual Carcass Measurements versus Optimal Carcass Measurements from the Simulation

	Mean	Std Dev	Min	Max
Actual carcass (pounds)	760	87.14	450	1,056
Optimal carcass (pounds)	826	75.67	292	909
Actual backfat (inches)	0.36	0.17	0.04	1.32
Optimal backfat (inches)	0.45	0.11	0.04	0.73
Actual marbling score[a]	sm 20	0.85	tr 40	ma 80
Optimal marbling score	sm 50	0.93	tr 40	a 30

[a] Abbreviations denote marbling scores of small (sm), traces (tr), moderately abundant (ma), and abundant (a).

not been measured in previous studies and is the most important finding of this research. The small number of animals within a pen that were fed too long result in discounts that were greater than the sacrificed gains on the other animals not being fed long enough. Sorting technology is able to capitalize on the inefficiency and potentially improve short-run returns.

Table 2 presents the characteristics of the actual carcass data and carcasses at optimal marketing dates. Individual animals sold at optimal dates reveal the maximum potential of ultrasound and sorting. The average weight in the actual carcasses was 760 pounds. The average weight for animals optimally marketed increased to 826 pounds. The standard deviation of the sorted cattle is 11.5 pounds or 13% smaller. Carcass weights were more consistent. There were fewer heavyweight, but more lightweight, "out" carcasses.[8]

Average backfat measurement in the actual carcasses was 0.36 inches, which the average backfat measurement for animals optimally marketed increased to 0.45 inches. But, the standard deviation of the sorted cattle was 65% of unsorted pens. Carcass red meat yields were more consistent. There were fewer poor yield grade cattle, and increases in backfat increase the risk of a poor yield grade discount, but this change is not enough to incur the discount. Through sorting, the cattle feeding enterprise grows individual cattle to heavier weights, with increased backfat, but not to the point where discounts occur.

The average marbling score increases, but the variation in scores increases as well. Cattle were less consistent in terms of marbling. However, the sorting and optimization program balances the trade-off between yield grade and quality grade. Longer feeding periods increase weight and marbling but also increase backfat. The ultrasound technology is able to find the cattle that will marble without excessive backfat, and the sorting system keeps those cattle on feed longer. Cattle that are only likely to marble after deposition of excessive backfat are sold earlier. These poor yielding animals will incur revenue penalties and will consume relatively large amounts of feed. This result shows the importance of including marbling measurements in ultrasound and sorting systems.

Sorting cattle results in higher average carcass weights, higher average marbling scores and USDA quality grades, and higher average backfat measurements but lower USDA yield grade scores. The increased backfat is not enough to incur a discount. Sorting reduces realizations in the problem tail of the weight and yield grade distributions.

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[8] For example, the smallest animal sold in the simulation had a carcass weight of 292 pounds and a live weight of 520 pounds. This specific animal had relatively large backfat deposition and almost no marbling—a poor yield grade and a poor quality grade. The sorting and optimization program instructs the cattle feeding enterprise to market this animal as soon as possible. This animal is an inefficient user of feed and a producer of poor quality beef. In actuality, this animal was sold as part of a pen, it graded USDA standard and yield grade 4, and was at a much heavier weight. These animals persist in the industry. The audits finds seven of these animals are present out of 10,000 in 1995 and finds 22 out of 10,000 in 2000 (Boleman et al.; McKenna et al.). There is one animal in approximately 7,000 in the Gelbvieh Alliance data.
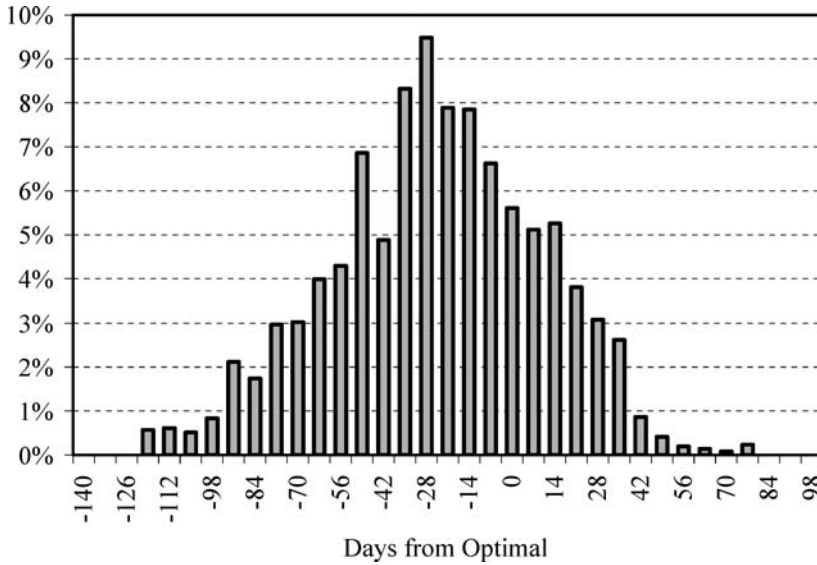
Figure 2. Difference between the Optimal Marketing Date and the Actual Marketing Date

The minimum economic potential associated with use of ultrasound technology is limited because the value of ultrasound comes from sorting and changing the composition of cattle within pens. This is information that grid pricing research cannot measure if the composition of animals within pens is ignored. Further, this is information that past research cannot measure if animal characteristics are not allowed to change through feeding longer or shorter periods.
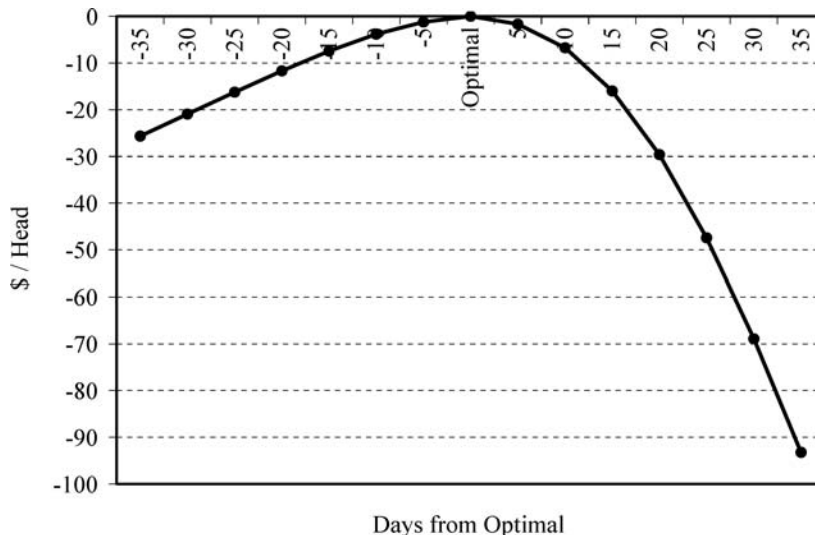
Within the constraints of the current marketing system, enterprises are underfeeding pens to avoid penalties. However, within any pen, there remain individual animals that are overfed. Both of these are seen in Figure 2, where optimal days are compared to the actual days for each animal in the sample. The distribution is shifted left in that most

Table 3. Returns to Sorting Animals within Pens Based on Weight and Ultrasound

Number of Sorts	Total Returns ($/Head)	Marginal Returns ($/Head)
Two	$15.59	$15.59
Three	$21.46	$5.87
Four	$24.05	$2.59
Five	$25.66	$1.61
Optimal	$30.08	—

animals are fed fewer days than optimal. This result is also seen in the average difference between actual and optimal marketing dates, in absolute value, which is 32 days. The average animal is marketed one month away from the optimal date. This is a substantial inefficiency that offers opportunity to producers that adopt sorting.

Table 3 presents the returns to various sorting regimes. Each sorting regime was compared to the 84-day baseline so that only sorting returns are reflected. The four additional days are not the source of any additional returns. The maximum returns to ultrasound and sorting is $30.08 per head. This involves marketing each animal at that animal's optimal date. This is the maximum return cattle feeding enterprises could expect from a perfect sorting and value-based marketing plan. Table 3 also presents the results to sorting the original pen into two, three, four, and five pens. Sorting into two pens returns $15.59 per head, three pens returns $21.46, four pens returns $24.05, and five pens $25.66 per head. Sorting exhibits decreasing marginal returns. The majority of the gains are exhausted after three sorts. This is intuitive. Three sorts results in marketing the animals in the pens that have the potential to be overfed first before they are overfed and discounts

Figure 3. Dollars per Head Opportunity Costs Associated with Marketing Fed Cattle at Various Days Different from the Optimal Date

occurred, marketing the animals in the center of the distribution close to the original date, and marketing the animals in the pens that have the potential to be underfed after longer feeding and capturing remaining economies of growth.

Lusk et al. state that 80-day deterministic backcast results in our work overestimating the returns to sorting. This may not be the case. There is only systematic error in the backcast if there are biases in the models used in the UCSS, and biases are unlikely. Unsystematic error in the backcast actually creates more a heterogeneous composition of animals within pens, which the UCSS would measure at reimplant, and the increased heterogeneity would increase the returns to sorting. The issue is not the potential error in the backcast but whether the carcass sample from the backcast is representative of animals within commercial feedlots at reimplant. Summary statistics of carcass characteristics are generally not reported for ultrasound measurements taken at reimplant. There is much information about ultrasound measurements immediately prior to slaughter. Comparison of the backcast sample to samples of field trials reported in Brethour (1989, 1991, 1995) reveals strong similarities. The backcast sample has similar summary statistics as field trial samples. We

also argue that the participants in the Gelbvieh Alliance have better and more uniform cattle than the general population of cattle. This is supported by comparing the distribution of quality attributes to the audit data. But after all this is said, the argument remains unresolved. Whether or not simulation can accurately measure the returns to sorting awaits a controlled sorting experiment using a large and representative sample of industry cattle.

Figure 3 presents the average opportunity cost per head as cattle are marketed earlier and later than the optimal marketing date. The UCSS was run where all the animals in the sample were marketed from 35 days early to 35 days past the optimal marketing day in intervals of five days. The average difference in the returns relative to the return on the optimal day was calculated and reported in Figure 3. Opportunity costs associated with overfed animals are greater than the opportunity costs associated with underfed animals. This figure shows the asymmetric nature of the premiums and discounts. When marketing a pen of cattle, cattle feeding enterprises will err on the side of underfeeding to avoid discounts on some of the animals in the pen.

Table 4 presents the percentage of carcasses within each of the USDA yield grades and

Table 4. Percentage of Carcasses in the Different USDA Yield Grade and USDA Quality Grade Categories between the Optimal Marketing and the Actual Marketing

Categories	Actual (%)	Optimal (%)
USDA yield grade		
1	3.81	1.09
2	75.42	47.20
3	20.34	51.71
4 and 5	0.43	0.00
USDA quality grade		
Prime	1.03	2.05
Certified	13.79	23.76
Low-choice	35.94	42.73
Select	46.56	29.58
Standard	2.68	1.88

quality grades for the actual data and for the maximum potential. Ultrasound and sorting allow cattle feeding enterprises to reduce the number of carcasses with poor yield and quality characteristics and increase the number of carcasses capturing yield and quality premiums.

Costs of Sorting

The main cost of sorting, that the activity likely requires a change in the cattle feeding enterprise's management philosophy, will be discussed later. Short of that, there are two costs: a marginal cost to evaluate the animal at reimplant and a marginal cost associated with adopting a sorting system.

The UCSS sorts animals at reimplant so the animal is already being handled. The animal is weighed and ultrasound measurements are taken. Ultrasound technician fees are approximately $3 per head, and record keeping expenses are approximately $1.50 per head. Ultrasounding slows animal processing from 2 head per minute to 1.5 head per minute and therefore increases labor costs. Processing 300 head, normally a 2.5 hour job, would require 50 additional minutes. A typical processing crew is three people. Depending on the wage rate, labor costs per head increase $0.15. Thus, the variable cost portion of the

marginal cost of sorting is approximately $4.65 per animal.

Other costs of sorting emerge if the activity reduces the total number of animal days on feed or results in additional empty pen space. Fixed costs of the cattle feeding enterprise must then be allocated over fewer animal days. The sorting system cannot result in smaller than truckload or infrequent sales. Sorting will likely be, and is, adopted by larger commercial cattle feeding enterprises. Five truckloads daily for 250 business days per year results in an average annual marketing of approximately 50,000 head and a one time feed yard capacity of approximately 20,000 head. These enterprises currently market over 50% of the fed cattle in the United States (USDA). Second, sorting actually results in most individual animals being fed longer (Figure 2). Therefore, the feeding enterprise will receive more daily yardage fees for each animal fed. The issue is: does sorting change the percentage capacity use by the feed yard?

Assume a 20,000 head capacity feed yard that has $1.8 million in overhead per year. The feed yard operates at an industry average of 80% capacity per year and has a 2.5 turnover per year, or typically feeds animals for 146 days. The overhead costs that must be covered by yardage are $45/head, or $0.31/head/day. Suppose the feed yard adopts a sorting system and this system results in cattle being fed two more weeks on average. The turnover will reduce to 2.3 times per year, but there is the same number of animal days to bill yardage. The question remains: does sorting reduce the percentage capacity use? It is unlikely that the feed yard will be severely space constrained with an industry average 80% capacity. But the industry average is 80% in part because of seasonal variation in feeder animal supplies.

Assume every pen is sorted three times and use an industry average 90 head pen. Suppose sorting results in one alternative marketing group being fed 14 fewer days, the next being fed 14 more days, and the final being fed 28 more days. This is consistent with Figure 2. There are 13,980 animal days on feed for this sorted 90 head pen. The capacity of that pen is 15,660 animal days, so sorting reduces capac-

ity use of that pen to 89%. There is empty space within the pen while the animals are on feed, and the pen remains empty for some portion of time between marketing and refilling. Assume these are the same as without the sorting system. The capacity use of the feed yard is then 89% of 80% or 71%. Reducing capacity from 80% to 71% increases fixed costs that must be allocated to each animal by $5.70 per head. This is the marginal increase in fixed cost of adopting the sorting system.

However, if sorting is combined with a formula marketing arrangement and supply chain management is improved, or the number of days the pen is empty is reduced, then the capacity use can be increased. One reason that the average industry capacity is 80% is because of the uncertainty of marketing dates for pens. With uncertain marketing dates, slack capacity is required between marketing and procurement of replacement animals for given pen space. Formula marketing results in improved knowledge of sale dates that can be used to reduce slack capacity. If percentage capacity use increases to 90%, then the reduction due to sorting (89%) will result in the same level of fixed costs allocated per animal (i.e., 89% of 90% is 80%). This is the change in management approach: a sorting system paired with improved capacity use.

In short, it does not appear that the fixed cost component of sorting will be larger than the variable cost component. Or, total costs of sorting are less than the $15–$25 return. However, there is considerable flexibility in implementing sorting systems, and this flexibility impacts cost.

Conclusions

There appear to be potentially large gains to be made from sorting fed cattle using weight and ultrasound measurements at the reimplant phase of feeding into more uniform marketing groups. Sorting returns $15–$25 per head in simulations based on the UCSS technology. These returns are large in an industry where average profitability is close to zero. Costs of sorting are reasonably between $5 and $11 per

head. This research is an important discovery and suggests that the cattle feeding industry should examine this method of improving efficiency.

Ultrasound technology appears to be beneficial to the fed cattle industry when paired with sorting. The benefits are gained when heterogeneous groups of cattle are sorted into more homogeneous groups. Sorting improves meat quality, consistency, and feed use efficiency. Sorting cattle from one group into two captures 50% of the value. Sorting into three groups captures 66% of the value. Thus, sorting exhibits diminishing returns, and simple sorting regimes capture most of the benefits. The efficiency gains are also gains to the industry in terms of improving competitiveness relative to other meats and are gains to the economy from better use of resources. Interestingly, the current practice of selling cattle based on visual examination appears to be accurate given the pen structure. Thus, sorting addresses the tails of the distribution of animal quality within a pen.

Most important, and unlike much other research, the returns to sorting are not due to exploiting price differences across marketing methods. Returns are the result of eliminating inefficiency and not the result of exploiting a trading partner. Returns are due to the production activity of sorting and will persist until the cattle population is more uniform in meat quality characteristics. This work is different from other research in that we allow the animal characteristics to change. Sorted cattle may be sold sooner or fed longer. No grid pricing research does this. We recognize that individual animals may be valued in a transaction, but the individual is sold as part of a group, and the marketing decision is optimized for the group and not necessarily the individual. Past research does not recognize a main constraint facing feedlots: that individual animals are sold in groups. The issue is the composition of animals within a pen.

It is important to recognize that returns to sorting will not persist in the long run. Cattle feeding has low barriers to entry, and pure

profits cannot persist. Profitability gains will be gathered by first adopters. It is unlikely that the profits we measure will persist once sorting is an industry standard, but the cattle industry is currently quite some distance from this standard. We also recognize that sorting technology is proprietary and patented. Some portion of the gain will be economic rent to the creators of this knowledge. However, there is a welfare gain in that meat quality will change and be improved—this is a permanent gain due to the sorting activity—and improving meat quality can only improve beef demand. Identification of potential sources for efficiency gains is important for the beef industry. Improvements by pork and poultry industries are well documented and well known and impact the long-term competitiveness of the beef industry (Schroeder, Mintert, and Brester).

Caution is warranted in the literal use of the returns to sorting found in this research. This type of caution is always warranted in analyses based on simulation methods. We think the results are useful from the standpoint of the sample representing the distribution of cattle found in innovative commercial feeding enterprises. Likewise, implicit in the use of growth and development models from the UCSS is that those models accurately describe the growth and development of the cattle and beef carcasses. The returns to sorting are contingent on the accuracy of those models and the prediction errors from the models. Communication with members of the cattle feeding industry that are sorting confirms the reasonableness of our results. The results are optimistic, and the next step would suggest controlled experiments with pens of cattle in commercial feeding environments.

Finally, this research reveals that use of ultrasound and sorting holds promise of improving the short-run profitability and long-run efficiency within the beef production system. Further, such changes will improve the quality of the product and may help address consumer demand problems. This is an important discovery that has not been measured in past research.

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