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Probabilistic Models of Yield, Price, and Revenue Risks for Fed Cattle Production

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Cattle feeding enterprises operate amid variability originating in prices and production. This research explicitly models yield risks related to cattle feeding by relating the mean and variance of yield performance factors to observable conditioning variables. The results demonstrate that pen characteristics, such as entry weight, gender, placement season, and location influence the mean and variability of yield factors, defined as dry matter feed conversion, average daily gain, mortality, and animal health costs. *Ex ante* profit distributions, conditional on cattle placement characteristics, are derived through simulation methods to evaluate the effects of price or yield shocks on the distributional characteristics of expected profits.

Key Words: conditional variance, production risk, cattle feeding, yields

JEL Classifications: D24, D81, Q12

Cattle feeding is a risky venture where returns oscillate from large profits to heavy losses over short time periods. Figure 1 illustrates wide swings in monthly average net returns for feeding cattle in Kansas from 1981 to 2006. During the first few months of 2001, cattle feeders were making about $70 per head, while by November of that year they were losing over $170 per head and these losses were sustained for 16 consecutive months. Even more striking is that the variability in net returns to feeding cattle has nearly doubled in recent years, with a standard deviation of $54 per head from 1990 to 1997, increasing to $93 per head from 1998 to 2006. Concurrent with increasing cattle feeding risk, cow-calf producers and farmer-feeders are seeing enhanced incentives to retain ownership to more directly connect selling prices to the quality of meat produced by their calves.

To develop effective risk management strategies, cattle feeders need to know the individual magnitudes of factors contributing to profit variability such as price and yield risk. Price risk occurs from movements in fed and feeder cattle prices, as well as the price of feed, while yield risk is a function of animal health and feeding performance. Two direct measures of cattle production yield are dry matter feed conversion, the amount of feed consumed by the animal per pound of weight gained, and the average weight gain per day. Other information, such as

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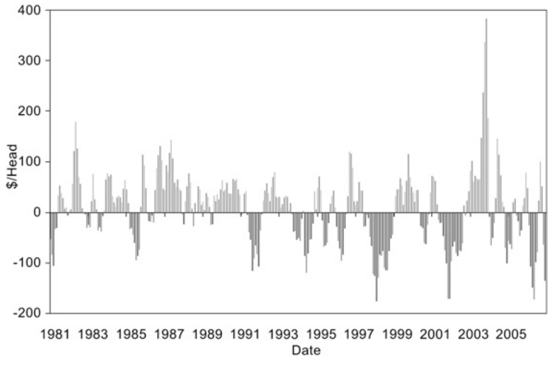

Figure 1. Estimated Monthly Cattle Feeding Returns 1981–2006—Note: Data Compiled and Provided by R. Jones, Kansas State University Research & Extension

mortality losses and the costs associated with veterinary medical services, reflect the health and vitality of the animal and provide indirect measures of yield performance. Empirical analysis of yield factors as well as feed costs and cattle prices will allow for a better understanding of how factors contribute to the overall distribution of profits from cattle feeding.

The objective of this paper is to characterize yield risks associated with fed cattle production. The analysis is motivated by a need to develop a model of *ex ante* risks associated with cattle feeding. *Ex ante* risks refer to measures that allow a conditional prediction of risks associated with yield outcomes at some time in the future. In this context, an important distinction is made between observable conditioning factors relevant to risk at the time decisions are made and other factors that represent random components of risk. Cattle feeding conditioning factors include variables that are known to the feeder at the time cattle placement decisions are made (e.g., placement weight, date of placement, feeding location, gender of animals, and feeder cattle prices). This research constructs a model of overall fed cattle profit risks, providing conditional forecasts of expected profits and other random variables to assign a measure of variability to these random outcomes. Within this framework, a number of conditioning factors are considered as well as several random factors which influence profitability.

Models are estimated for production yield variables that provide distributional properties of production risk. The models condition performance and risk measures on certain variables that can be controlled by cattle feeders, such as date of placement on feed, cattle gender, average placement weight, and feeding location. By accounting for deterministic factors, estimates of the conditional mean and variance of each variable are computed to describe the risks of cattle yields. This information, as well as estimates of feed costs and fed cattle prices, provides the basis for estimating distributional characteristics of *ex ante* profits from cattle feeding.

An extensive literature has examined models of crop yield and price risk (see the survey of Goodwin and Ker). Until recently, agricultural insurance in the United States has been confined to the coverage of crop yield risks. However, the 2000 Agricultural Risk Protection Act mandated development of new insurance products, including coverage for livestock. This impetus heightened the importance of empirical research addressing models of livestock yield risk. To date, risk management instruments resulting from this legislation have focused on price risk and largely ignore risks associated with cattle yields. For example, Hart, Babcock, and Hayes developed livestock revenue insurance products that protect against adverse swings in corn and fed cattle prices, but spent little time discussing production risk.

Cattle yield or feeding performance has been considered in several empirical studies that focused on estimating the individual effects of prices and yield factors on cattle feeding profits (Schroeder et al.; Langemeier, Schroeder, and Mintert; Lawrence, Wang, and Loy; and Mark, Schroeder, and Jones). While these studies generally found cattle and corn prices to be a large contributor to cattle feeding profits, production risk factors were found to vary based on location and pen-level characteristics.

The risk associated with retaining ownership during the feeding period has been evaluated by White et al. and Wang et al., as well as Falconer, Long, and McGrann. While Wang et al. account for the distributional characteristics associated with production and price risk components, production components are not conditioned on pen-level characteristics. This study, as well as the others previously mentioned, illuminates the importance of this component. White et al. and Wang et al. show that under certain instances it might be advantageous to retain ownership throughout the feeding period, making studies that provide producers with more accurate depictions of the *ex ante* risks of more importance.

Past studies have quantified aggregate determinants of cattle feeding profit risk over long periods of time. As such, results provide important information about relative importance of factors contributing to cattle feeding net return variability over time. However, past studies have not developed models that at a point in time provide *ex ante* expectations of cattle feeding profit variability given information available at placement. That is, when a cattle feeder places cattle on feed at that point in time they make several decisions that condition the expectation and the amount of risk they face associated with input and output prices and cattle feeding performance. Conditioning variables and their relative impacts on expected profit and profit variability change with cattle placement weight, cattle gender, feeding location at any point in time. This study specifically develops and estimates models that provide *ex ante* profit and profit risk estimates for a pen of cattle given conditioning factors present. As such, the models estimated here provide the foundation for generating expected profit outcomes for a pen of cattle at placement conditioned on placement weight, cattle gender, feeding location, and expected market conditions.

Modeling Cattle Yields

Although several studies have included feed conversion and average daily gain in profit variability modeling, health measures like mortality losses and veterinary costs have not been explicitly considered. Further, joint models of the overall determinants of profit risk of the type applied in this study have not been evaluated in other work. In this study, the overall performance of a pen of cattle is measured by dry matter feed conversion (DMFC), which is a ratio indicating the amount of feed required per pound of weight gain, average daily weight gain (ADG), veterinary costs per head (VCPH), and the mortality rate of each pen (MORT). Each of these variables describes different aspects of overall cattle yields and therefore cattle feeding yield risk.

To estimate the density associated with various measures of cattle yields, models for each measure must be specified to account for deterministic factors (decision variables) involved in cattle feeding. The underlying motivation of these models is to derive conditional probabilistic measures of the distributional properties of yield factors. In deriving distributional parameters, the proposed model allows conditioning variables to influence the mean and variance. The first step of the analysis involves identification of relevant conditioning variables that may be associated with risks of cattle production yield but are of a deterministic nature. These conditioning variables need to be observable at the time relevant production decisions are made or at the point in time when an insurance contract or other risk management instrument is offered (i.e., prior to placement on feed). Conditioning variables such as seasonal effects, pen characteristics, and feedlot-specific fixed effects are included in our empirical models for DMFC, ADG, MORT, and VCPH. Seasonal effects, represented by the date the cattle were placed on feed, account for some of the risks associated with seasonal weather and other environmental factors. Cattle characteristics, such as gender and average placement weight, also represent important conditioning factors relevant to differences in yield for various pens of cattle. Feedlot-specific characteristics affect risk through differences in geographic location, feedlot management practices, or the predominance of certain breeds of cattle being fed at different locations. Using measures of these conditioning variables, the general forms of each model for yield factors are:[1]

[1] As we note below, these factors are certainly interrelated and thus joint estimation may offer efficiency gains. We parameterize this correlation structure subsequent to estimation and conduct risk simulations using this parameterized correlation structure. We do not pursue joint estimation in light of the complexity associated with censoring (in the mortality case) and because of our desire to allow the variance terms to depend on the conditioning factors.

(1) *DMFC* = f_1(*gender, location, in-weight, season*)
(2) *ADG* = f_2(*gender, location, in-weight, season*)
(3) *MORT* = f_3(*gender, location, in-weight, season*)
(4) *VCPH* = f_4(*gender, location, in-weight, season*)

The conditioning variables in each model are: *gender*, binary variables for steers, heifers, or mixed sex; *location*, binary variables for feedlot location; *in-weight*, the average placement weight; and *season*, binary variables determined by the placement month.[2]

We hypothesize that these conditioning factors influence mean yields as well as the conditional variability associated with each yield measure. In the presence of heteroskedasticity, ordinary least squares estimates will remain unbiased, but less efficient than estimators that control for the influence of independent variables on the variance. Furthermore, in this study where we consider the mean and variance associated with each risk factor, accurately estimating the variance associated with each set of independent variables is essential. In addition, allowing independent variables to influence the variance offers insights into how changes in placement characteristics lead to more or less risk. Thus, each regression is estimated using Harvey's multiplicative heteroskedasticity model (Harvey), which offers unbiased and efficient estimates of the parameters with error terms that are independently distributed. The model is specified as

$$(5) \qquad y_i = \mathbf{x}_i' \beta + \varepsilon_i$$

where $\mathbf{x}_i$ is the vector of pen-level conditioning variables and $\varepsilon_i \sim N(0, \sigma_i^2)$. Specifically, $\mathbf{x}_i$ contains the individual characteristics of gender, feedlot location, entry weight, and season of placement used to explain risk associated with each dependent variable (*DMFC, ADG, MORT,* and *VCPH*). The conditional variance is unique for each observation and is estimated as

$$(6) \qquad \sigma_i^2 = \sigma^2 \exp(\mathbf{z}_i' \alpha)$$

where α contains parameter estimates for each explanatory variable that weigh each characteristic by its effect on the individual variance term and $\mathbf{z}_i$ contains conditioning variables that affect the variance. In this model, the variables are the same as those contained in $\mathbf{x}_i$, but without the intercept, which is captured by the σ^2 term.[3] Maximum likelihood estimation is used to estimate Harvey's model for *DMFC, ADG,* and *VCPH* by specifying the following log-likelihood function for the normal distribution $\log L(\beta, \alpha, \sigma^2) = -n/2 \log 2\pi - 1/2 \sum_{i=1}^{n} [\ln(\sigma^2) + \mathbf{z}_i' \alpha] - 1/2\sigma^2 \sum_{i=1}^{n} (y_i - \mathbf{x}_i' \beta)^2 / \exp(\mathbf{z}_i' \alpha)$. Note that the variance is no longer assumed to be constant across observations, but rather depends on the explanatory variables, $\mathbf{z}_i$.

Not every pen of cattle in the data set realized mortality losses, so the value for *MORT* is censored at zero for approximately 46% of the observations in the data. Therefore, the multiplicative heteroskedasticity model for *MORT* is estimated as a Tobit model. Accounting for heteroskedasticity in the Tobit model is particularly important, given that, unlike ordinary least squares, Tobit estimates are also biased when heteroskedasticity is not accounted for in estimation (Hurd). In using a Tobit model with multiplicative heteroskdasticity, the obtained estimates are unbiased and more efficient than simple Tobit estimators, when errors are heteroskdedastic. Maximum Likelihood estimation is used to estimate Harvey's model for *MORT* by specifying the log-likelihood function from the Tobit model with multiplicative heteroskedasticity, which can be written as

[2] Interaction terms, as well as a time trend, were also included in initial regressions, but did not significantly alter the results or improve the model fit substantially.

[3] Note that a separate, additive intercept term cannot be identified in this specification, since σ^2 is a parameter that must be estimated.

$$\log L = \sum_{\forall d_i > 0} -\frac{1}{2}\left[\log 2\pi + \ln(\sigma^2) + \mathbf{z}_i'\alpha + \frac{(y_i - \mathbf{x}_i'\beta)^2}{\sigma^2 \cdot \exp(\mathbf{z}_i'\alpha)}\right] + \sum_{\forall d_i = 0} \ln\left[\Phi\left(\frac{-x'\beta_i}{\sigma^2 \exp(\mathbf{z}_i'\alpha)}\right)\right]$$

where Φ is the normal CDF. The two parts of the likelihood function correspond to Harvey's model for the nonlimit observations (i.e., those with a positive death loss) and the relevant probabilities for the limit observations (i.e., those with zero death loss), respectively.

From Equations (5) and (6), the expected conditional mean and conditional variance of each production yield variable can be calculated for each observation. These values provide a description of the risk associated with each variable faced by cattle feeders at the time cattle are placed on feed. These values can be incorporated into an estimate of *ex ante* expected profits, which is also a function of expected means and expected variances for feed costs and fed cattle prices, conditional on factors observable at the time the cattle are placed. This provides both an estimate of the overall expected variability in profits prior to placing cattle on feed and the impact of individual factors such as prices and yield on expected profits and profit variability.

Data

The empirical analysis is applied to a comprehensive set of data collected from five cattle feedlots located in Kansas and Nebraska. Proprietary production and cost data were obtained for 11,993 pens of cattle from 1995 to 2004. Table 1 contains summary statistics for the data sample. Dry matter feed conversion (*DMFC*) measures the pounds of dry feed required per pound of live weight gain and is calculated by dividing total dry feed used by total weight gained in the pen during the feeding cycle. Average daily gain (*ADG*) captures the average weight gain per head per day, which is calculated based on the difference between total weight of the entire pen of cattle upon entry and exit of the feedlot. Veterinary costs per head (*VCPH*) are calculated by dividing the total dollar amount spent on veterinary services and medications by the number of head sold from the pen. Mortality rate (*MORT*) is a percentage calculated as the number of death losses during the feeding period divided by the number of head initially placed on feed. The size of a pen of cattle averaged 134 head with an average placement weight of 747.3 pounds and an average finished weight of 1,184 pounds. *In-Weight* is measured as the average weight per head in each pen upon placement on feed.[4] The natural log of *In-Weight* is used in each of the three models. To capture seasonal effects, placement dates are measured using binary variables denoting *Winter*, *Spring*, *Summer*, and *Fall* placement.[5] Binary variables are also used to differentiate pens by gender (*Steers*, *Heifers*, *Mixed*) and feedlot location (*KS* and *NE*).

Estimation Results

Likelihood ratio tests were first conducted in order to determine the appropriateness of assuming multiplicative heteroskdasticity. In order to conduct this test, we constructed a restricted model where the conditional variables have no impact on variability, which can be stated as $\alpha = \underline{0}$. Likelihood ratio test statistics shown in Table 2 strongly support the hypothesis that variability is impacted by the conditioning variables.

The maximum likelihood estimates of parameters relating to *DMFC*, *ADG*, *VCPH*, and *MORT* were determined assuming multiplicative heteroskedasticity and running four individual regressions. Following are results from each production yield regression.

[4] Pens with average placement weights below 500 lbs and above 1,000 lbs were excluded from our sample since they were not found to align with the vast majority of observations. Major differences in these observations, relative to the rest of the data, were found in the days on feed, mortality rates, pen size, location, and season of placement. The elimination of these observations reduced the sample by 1.9%.

[5] Seasons are split into Winter (Dec–Feb), Spring (Mar–May), Summer (Jun–Aug), and Fall (Sep–Nov).

Table 1. Variable Descriptions and Summary Statistics

Variable Name	Description	Mean	Standard Deviation	Minimum Value	Maximum Value
DMFC	Dry Matter Feed Conversion (lbs feed/lbs gain)	6.21	0.72	4.39	23.84
ADG	Average Daily Gain (lbs gain/day)	3.37	0.49	0.74	5.78
VCPH	Veterinary Cost Per Head ($)	11.69	6.19	0.00	60.00
MORT	Percentage of pen that die	0.92	1.52	0.00	25.83
In-Weight	Average weight per head of cattle for the entire pen mesured upon entrance (lbs)	747.28	95.35	500.00	1000.00
OutWt	Average weight per head of cattle for the entire pen measured upon exit (lbs)	1,183.83	90.75	910.00	1472.00
Winter	Binary variable equal to 1 if entry was between Dec–Feb	0.25	0.43	0.00	1.00
Spring	Birnary variable equal to 1 if entry was between Mar–May	0.23	0.42	0.00	1.00
Summer	Birnary variable equal to 1 if entry was between Jun–Aug (base category)	0.26	0.44	0.00	1.00
Fall	Birnary variable equal to 1 if entry was between Sep–Nov	0.25	0.43	0.00	1.00
Steers	Birnary variable equal to 1 if entire pen of cattle were steers	0.53	0.50	0.00	1.00
Heifers	Birnary variable equal to 1 if entire pen of cattle were heifers (base category)	0.36	0.48	0.00	1.00
Mixed	Binary variable equal to 1 if pen was mixed gender	0.12	0.32	0.00	1.00
KS	Binary variable equal to 1 if Kansas feedlot	0.80	0.40	0.00	1.00
NE	Binary variable equal to 1 if Nebraska feedlot (base category)	0.20	0.40	0.00	1.00

Note: Total sample size n = 11,993 pens of cattle.

Dry Matter Feed Conversion Model

Table 3 shows the maximum likelihood estimation (MLE) results of Harvey's model for Equation (1). The use of MLE to obtain parameter estimates for *DMFC* requires the assumption of a parametric distribution for the error terms. After conditioning out the deterministic factors, *DFMC* residuals appeared to be most closely characterized by a log-normal distribution. This is reflected in a substantial degree of positive skewness in the distribution of residuals from an initial regression of the level of *DFMC* on the conditioning variables. Therefore, a normal likelihood function is used, where the dependent variable is the natural log of *DMFC*.

The signs of the coefficients for *Steers* and *Mixed* pens indicate that heifers have higher *DMFC* rates than the other two types of pens. This suggests that pens of all steers are 7% more efficient at feed conversion overall than heifer pens

Parameter estimates for the *KS* binary variable indicate that *DMFC* is 13% lower for the Kansas feedlots relative to the Nebraska feedlots, which is likely the result of different management practices or environmental factors. Pens of cattle fed in Nebraska in our sample typically have lower placement weights and higher finished fed cattle weights, with an additional 25 days on feed.

The coefficient for the log of *In-Weight* indicates that a 10% increase in average *In-Weight*, corresponds to a 2.0% increase in *DMFC*. This finding is supported by previous literature (Schroeder et al.; Mark, Schroeder, and Jones), which suggests that heavier

Table 2. Likelihood Ratio Test Results

Model	DMFC	ADG	MORT	VCPH
Unrestricted	12,102	−6,403	−17,959	−6,156
Restricted	11,834	−6,584	−18,268	−6,427
LR Statistic (df = 7)	536	363	624	541
P-value	< 0.001	< 0.001	< 0.001	< 0.001

placement weight cattle have a higher DMFC rate (i.e., they are less efficient at feed conversion) than lighter-weight placed cattle. Mark and Schroeder state that the optimal cattle performance typically occurs within a temperature range of 40–60°F. Temperatures outside of this range reduce cattle feeding performance. Specifically, higher temperatures lead to decreased weight gain from lower feed consumption, while colder temperatures increase maintenance energy, leading to higher conversion rates. Increased variability in weather and precipitation can also reduce performance. The coefficient for *Winter* is not significantly different from *Summer*. Since both months are outside of the range of optimal feeding, cattle may realize similar feeding performance in the hot summer as in the colder winter in these climatic regions, although for different reasons. *Spring*, which has average monthly temperatures well within the range of optimal feeding in this region, has a significant negative coefficient. This implies that the same pen of cattle started on feed in the spring, as opposed to summer, is likely to experience lower DMFC (i.e., the spring placed pen will be more efficient at converting feed into weight gain). Pens in this data set averaged nearly 129 days on feed, implying that most observations straddle two different seasons. The parameter estimate for *Fall* indicates that cattle entering during fall are less efficient at feed conversion. However, *Fall* placements are typically on feed during fall and winter months, during which extreme temperature and precipitation conditions can occur in both Kansas and Nebraska. This may cause *DMFC* to be higher than in any other season.

Table 3 also includes the conditional variance MLE results for *DMFC*. Equation (6) describes the linear equation used to estimate these variances by observation. The heteroskedasticity parameter estimates offer insight into how conditioning variables affect variance. The intercept term can be directly interpreted as σ, according to Equation (6). *Log(In-Weight)* has a significant positive correlation with higher variance in *DMFC*, implying that heavier-weight placed pens have more variable feed conversion rates. More specifically, a one percentage point increase in placement weight coincides with a 0.76% increase in variance.[6] Lighter-weight placed pens are generally on feed for a longer time period and, as such, they are more likely to face both favorable and unfavorable growing conditions that tend to offset each other. In contrast, cattle that are on feed for short periods of time (i.e., heavy-weight placements) might enjoy a short period of favorable growing conditions or a short period of very unfavorable conditions and, as such, heavier-weight placements realize greater DMFC variation over time.

Heteroskedastic parameter estimates offer information into the effect of the variable on conditional variance.[7] For example, the parameter estimate for *Steers* implies a 7% smaller conditional variance for steers relative to heifers, while *Mixed* pens present the highest variance by gender which may be because of different steer-to-heifer proportions in these pens. There is not a significant difference between *Winter* and *Summer*, while *Fall* and *Spring* both

[6] Given Equation (6) and that weight is in log form, an elasticity, relative to placement weight, can be directly interpreted from the conditional variance parameter since $\partial\sigma_i^2/\partial(Log(weight))1/\sigma_i^2 = \alpha$.

[7] Evaluating the effect that a positive binary variable, say X_k , has on the conditional variance for a given observation with k parameters can be illustrated with the following equation: $\sigma_i^2|_{X_k=1} - \sigma_i^2|_{X_k=0} = \exp(\bar{X}_1\alpha_1 + \cdots + \bar{X}_{k-1}\alpha_{k-1}) \times [\exp(\alpha) - 1]$. From this equation, it can be shown that the difference in conditional variance will be positive when $\alpha > 0$ and negative when $\alpha < 0$.

Table 3. Harvey's Model Results for Log of Dry Matter Feed Conversion

	Conditional Mean		Conditional Variance	
Variables	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error
Constant	0.6062*	0.0449	0.0075*	0.0020
Steers	−0.0697*	0.0018	−0.0733*	0.0211
Mixed	−0.0262*	0.0035	0.4974*	0.0260
KS	−0.1228*	0.0022	−0.1420*	0.0260
Log(In-Weight)	0.2031*	0.0069	0.7599*	0.0809
Winter	0.0002	0.0024	0.0182	0.0249
Fall	0.0518*	0.0026	0.3401*	0.0250
Spring	−0.0163*	0.0022	−0.3518*	0.0268
LL	12,102.0822			
R-Square	0.3173			

* Denotes estimate is statistically significant at the 5% level.

present significant differences in individual variability when compared with *Summer*. Pens placed in fall are associated with 34% more variance than summer, which is largely due to the occurrences of extreme weather in winter.

Average Daily Gain

Estimation results for the *ADG* equation are shown in Table 4. Most of the parameter estimates for *ADG* are consistent with, though with an inverse sign, to the results contained within the *DMFC* model. This is mostly explained by the high degree of correlation between the two variables. Parameter estimates indicate that *Steer* pens gain weight faster than heifer pens by 0.3 pounds per day, which is a 10% gain over the average heifer pen. Placement weight is positively correlated with *ADG* because heavier-weight placements are quickly stepped up to full-feed high energy feed rations (as opposed to lower energy growing rations) when placed in a feedlot. This result, combined with the higher feed conversion rate of heavy-weight placed pens, implies that pens with heavier placement weights are fed significantly more feed per day than those with lighter placement weights. Pens placed in summer months have greater gains than at any other time of the year (implying these animals are typically finishing during the late fall when climate in this region is generally near ideal for cattle finishing). Each conditioning variable has a significant effect on both the expected mean and variance of *ADG*.

Mortality Rate Model

Table 5 contains the MLE results for the model described in Equation (3), where mortality rate (*MORT*) is the dependent variable. Again, recall that the mortality rate is censored at zero, with many pens realizing no death losses. The coefficients for *Steers* and *Mixed* indicate that both types of pens have higher mortality rates than pens consisting of heifers only, by 0.15 and 0.44%, respectively.[8] The coefficient for *KS* indicates that there is not a statistically significant difference in mortality rates between Kansas and Nebraska feedlots. A one percentage point increase in placement weight is associated with a 0.03% decrease in the mortality rate. Placement date does not appear to have a statistically significant effect on expected mortality rate.

The conditional variance of *MORT* is described by the heteroskedasticity parameters also listed in Table 5. All the conditioning variables in the model have a statistically significant effect on the conditional variance of the mortality rate. Pens consisting of steers only have a negative impact on the conditional variance of the mortality rate, while pens of mixed gender have a higher conditional variance when

[8] To interpret the marginal effects within the Tobit model, parameter estimates must be multiplied by the proportion of noncensored observations in the sample (Greene, p. 766), which is 53.404% within this data set.

Table 4. Harvey's Model Results for Average Daily Gain

	Conditional Mean		Conditional Variance	
Variables	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error
Constant	−2.9563*	0.1940	0.0091*	0.0029
Steers	0.3067*	0.0082	0.1031*	0.0267
Mixed	0.1301*	0.0136	0.3357*	0.0386
KS	0.1783*	0.0099	−0.1377*	0.0310
Log(In-Weight)	0.9257*	0.0297	1.1614*	0.0968
Winter	−0.1759*	0.0105	−0.1214*	0.0329
Fall	−0.2233*	0.0113	0.2300*	0.0337
Spring	−0.0476*	0.0103	−0.2463*	0.0338
LL	−6,402.6469			
R-Square	0.2612			

* Denotes estimate is statistically significant at the 5% level.

compared with pens of heifers only. The coefficient for *KS* indicates that the conditional variance of the mortality rate is higher for Kansas feedlots, relative to Nebraska feedlots. The conditional variance of mortality rate is decreased by 1.5% as placement weight increases by one percentage point. The seasonal variables indicate a lower conditional variance for winter and spring placement and a higher variance of the mortality rate for fall placement, as compared with summer placement.

Veterinary Costs Model

Table 6 shows MLE results for the conditional mean model described by Equation (4), where the dependent variable is veterinary costs per head of cattle (*VCPH*). As with the *DMFC* model, *VCPH* is estimated using the natural log of *VCPH* as the dependent variable.

The coefficients for *Steers* and *Mixed* indicate that *VCPH* are 5% and 21% higher, respectively, as compared with pens of heifers. Higher steer pen veterinary costs may be partly due to the fact that steers are fed for an average of 4 days longer than heifer pens. Alternatively, higher veterinary costs may indicate poorer overall health of the pens, since *VCPH* is a proxy for the general health of a pen of cattle as demonstrated by steers also having higher mortality rates than heifers. To illustrate this magnitude, mixed pens average $14.49 in veterinary costs per head, compared with $11.81 and $10.97 for heifer and steer pens, respectively.

Feedlots in Kansas have lower *VCPH*, as compared with Nebraska feedlots. Lower

Table 5. Harvey's Model Results for Mortality Rate

	Conditional Mean		Conditional Variance	
Variables	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error
Constant	22.576*	1.3099	270.3596*	127.2912
Steers	0.1456*	0.0504	−0.0942*	0.0422
Mixed	0.4370*	0.1010	0.8180*	0.0609
KS	−0.0992	0.0511	0.2320*	0.0484
Log(In-Weight)	−3.3254*	0.1996	−1.4961*	0.1445
Winter	0.0896	0.0612	−0.2097*	0.0531
Fall	0.0629	0.0682	0.2348*	0.0525
Spring	−0.0592	0.0610	−0.3528*	0.0568
LL	−17,956.0000			
Psuedo R-Square	0.0401			

* Denotes estimate is statistically significant at the 5% level.

Table 6. Harvey's Model Results for Log of Veterinary Costs per Head

	Conditional Mean		Conditional Variance	
Variables	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error
Constant	10.5848*	0.1878	5.0434*	0.8630
Steers	0.0528*	0.0089	−0.3581*	0.0125
Mixed	0.2129*	0.0148	0.1887*	0.0279
KS	−0.2099*	0.0095	0.2323*	0.0147
Log(In-Weight)	−1.2233*	0.0286	−0.7900*	0.0511
Winter	−0.0763*	0.0105	0.2317*	0.0144
Fall	0.0087	0.0106	0.3284*	0.0170
Spring	−0.0732*	0.0103	0.0512*	0.0158
LL	−6,156.1681			
R-Square	0.1861			

* Denotes estimate is statistically significant at the 5% level.

spending on veterinary services per head may be due to differences in management practices, environmental factors, or a higher average of days on feed in Nebraska feedlots. The coefficient for *Log(In-Weight)* indicates that increasing placement weight by one percent leads to a decrease in veterinary costs by 1.2%. This is largely because pens with heavier placement weights spend less time on feed and more mature animals likely have more natural immunities. The coefficients of seasonal binary variables for *Winter* and *Spring* indicate a *VCPH* lower than summer placements by over 7%. The coefficient for *Fall* was not statistically different from *Summer*.

The heteroskedasticity parameters listed in Table 6 describe the conditional variance of *VCPH*. All the conditioning variables in the model have a statistically significant effect on the conditional variance of *VCPH*. Veterinary services are used as a precautionary measure through pretreating cattle and also are used in reaction to disease or injuries during the feeding cycle. Pens consisting of steers only have a negative impact on the conditional variance of *VCPH*, as compared with pens of heifers. The coefficient for *KS* indicates that the conditional variance of *VCPH* is higher for Kansas feedlots, relative to Nebraska feedlots. Similar to the results for mortality rate, the conditional variance of *VCPH* is lower for heavier placement weight cattle, as indicated by the negative coefficient for *Log(In-Weight)*. The seasonal variables indicate a higher conditional variance for all placement dates, relative to summer placement.

Profitability of Cattle Feeding

The conditional expected mean and variance of each of the yield factors describes the distributional characteristics of *DMFC*, *ADG*, *MORT*, and *VCPH* after accounting for information known prior to placing cattle on feed. These estimates can be combined with conditional expected means and variances for corn prices and fed cattle prices to characterize the conditional profit risk of cattle feeding. By analyzing profit risk in this manner, feedlot owners and others with a financial interest in cattle feeding can better understand not only the overall profit risk they face, but also the contributions of individual yield and price volatilities to that risk. Each of these individual sources of risk is potentially related to the others, such that any consideration of overall profit risk must consider the correlation structure inherent in the different risk factors. Although the conditional mean and variance equations were estimated individually, we estimated the correlation structure by considering the correlation among residuals from the estimated equations. In the risk simulations which follow below, we assume that the cross-equation correlation coefficients are constant at the values implied by the estimation sample. Thus, we alter the off-diagonal covariance terms in our simulations as the conditional variance terms change in a manner that holds the correlation coefficient constant.[9]

In order to model profit risk, a profit function must be used that accounts for the revenue and costs specific to cattle feeding. The expression for *ex ante* profits on a per head basis is $\Pi = TR - FDRC - YC - FC - VC - IC$, where Π is per head profits, *TR* is total revenue per head from cattle feeding, *FDRC* is the per head costs of purchasing feeder cattle, *YC* is the per head fixed cost (yardage cost) of feeding cattle, *FC* is the per head feed cost, *VC* is per head costs associated with veterinary care, and *IC* is an interest cost. *TR* is defined as $TR = FP \times CSW \times (1 - MORT) \times (0.96)$, where *FP* is the price per hundred weight ($/cwt) of fed cattle and *CSW* is the average sale weight of the finished cattle, which is estimated based on $CSW = CPW + (ADG \times DOF)$, where *CPW* is the average weight of the feeder cattle at placement and *DOF* is the number of days the pen of cattle is in the feedlot. *TR* is adjusted for death loss using the *MORT* variable and a standard 4% live-weight shrinkage factor is applied to reflect the expected loss in weight during transport from the feedlot to the packing plant. Sell weight is a function of a random performance variable (*ADG*) and therefore is not fixed. While expected days on feed is a direct input into the simulation, sell weight is determined by the average weight upon entry, random variable *ADG*, and the length of time on feed.

FDRC is defined as $FDRC = FRP \times CPW$, where *FRP* is the price per hundred weight of feeder cattle. *YC* is defined as $YC = (0.40) \times DOF$ where $0.40 is a typical per head day cost for feedlots in Kansas and Nebraska. *FC* is defined as $FC = CP \times 1/56 \times \{DMFC/0.88 \times ADG \times DOF\}$, where *CP* is the price per bushel of corn and is divided by 56 to convert this price into a per pound basis. Further, dry feed is multiplied by the corn-based feed ration, which is assumed to be 12% moisture. *DMFC* is adjusted to reflect the feed conversion rate that is based on the total amount of feed that is offered to the pen of cattle. *IC* is defined as $IC = \{1/2[YC + FC + VC] + FDRC\} \times DOF \times IR/365$, where *IR* is the interest rate. This expression assumes that an interest charge is applied to the full amount of the feeder cattle cost, *FRC*, and half the total cost of yardage, feed, and veterinary fees. This assumption is based on the need to purchase feed throughout the feeding period, while the feeder cattle must be entirely purchased at the beginning of the feeding period.

Within the context of our yield model for cattle feeding, six random variables are relevant as sources of profit risk. The four yield variables, *DMFC*, *ADG*, *MORT*, and *VCPH*, are modeled using the conditional mean and heteroskedasticity models discussed above. Unique pen characteristics define an expected mean and variance, which are then parameters of a normal distribution. Draws are then taken from these distributions to simulate realizations of the yield variables, taking into account the correlation structure. The other two relevant random variables are the expected values and variability of feed prices and the price of the finished commodity, fed cattle. Measures of the expected futures price of corn (an important indicator of feed prices) and fed cattle prices are available in futures markets. In addition, options contracts offer market-based measures of the conditional variability of expected future prices. Therefore, the futures and options contracts corresponding to the placement and finishing dates for a pen of cattle are used in the profit model simulations.

The standard Black-Scholes assumption of log-normality is used to derive distributional aspects of corn and fed cattle prices from the implied volatilities taken from options markets. The models of the four random yield variables, taken together with the log-normally distributed corn and fed cattle prices, allow us to derive an expression for the expected level of profits associated with any particular placement. The profit estimates are conditioned on the conditioning factors relevant to the yield

[9] The Pearson correlation coefficient is given by the ratio of the covariance to the product of the standard deviations. Thus, as the conditional variances (and thus standard deviations) change, the implied covariance terms are scaled to maintain constant correlation. This has the added advantage of maintaining a positive semidefinite conditional covariance matrix. Of course, it would be preferable to parameterize the entire covariance structure and allow all terms to vary with conditioning factors.

factors as well as on expected corn and fed cattle prices. The expected prices are represented by the futures price of the contract corresponding to the feeding period being considered. The expected mean of profits is a function of the variables described in the profit function, while the expected variance of profits is a function of the implied volatility of fed cattle and corn prices, and the variance of *DMFC*, *ADG*, *MORT*, and *VCPH*.

Simulations of profitability risk are conducted based upon the six-variable risk model. For a given set of conditioning variables, the conditional heteroskedasticity models are used to predict the conditional distributional characteristics associated with each yield factor. Although the variance terms are allowed to vary with the conditioning factors, the covariance terms are held fixed at the values implied by residuals resulting from model estimates. Zero correlation is assumed between the four pen-level yield factors and the corn and fed cattle prices. The correlation between the prices for corn and fed cattle is set to −0.16408, based on daily cash prices from 1980–2005. It is well-recognized that rank correlation is preserved by any monotonic transformation of random variables. Therefore, draws from a multivariate normal distribution can be used to generate correlated values with means and variances specified by the modeling framework with different marginal distributions for each of the six random variables. Simulation of the four yield factors proceeded following the method proposed by Fackler. For each realization of correlated variables, a profit realization is calculated. From a large number of simulated profit realizations (100,000 correlated random draws are used from the six variable system), it is possible to assess the distributional properties associated with expected profits. This process maintains the correlation structure inherent in the yield factors. For example, the simulation structure maintains the highly correlated relationship between *MORT* and *VCPH*, as well as *DMFC* and *ADG*.

Distributions for profit per head are simulated using the following scenario: a pen of steers placed on feed in a Kansas feedlot on May 20, 2008. The average placement weight of the pen is 750 pounds and the estimated number of days on feed for this pen 150 days.[10] The feeder cattle price used in the simulation is assumed to be $107/cwt, while the expected fed cattle price ($105.28/cwt) and expected corn price ($6.02/bu) were taken from futures contract prices for the contract ending October 2008 and September 2008, respectively (both adjusted for local basis using a three-year historical average for that time period). The October contract date was used for fed cattle to reflect the expected selling date, assuming that the cattle are fed for five months. Since the feed cost is incurred throughout the five month period, the September corn contract is used as a proxy for the average price of corn over the entire feeding period. The annual interest rate was assumed to be 8.0%. The sample mean of each conditioning variable is used in the yield models to obtain an expected mean and variance for *DMFC*, *ADG, MORT*, and *VCPH*.

To illustrate the effect on profit per head from changes in the variability of fed cattle prices, four separate simulations were run within the profit model. The four simulations reflect a high, average, and low risk scenario for fed cattle prices, as well as full price protection through the use of forward contacts. The high risk scenario was based on simulated prices with the implied volatility set to 30%. The low risk scenario was based on a volatility of 20% and the base level of volatility scenario was 27%, based on options premium rates. The forward contract scenario eliminates cattle price variability, making implied volatility equal to zero. Figure 2 illustrates the four simulations for fed cattle prices, while holding corn price at its base volatility level of 32% and holding everything else equal.

The simulation results indicate that increases in the live cattle price variance leads to a significantly wider distribution of profits. It is also notable that the recent increases in corn futures

[10] While factors such as placement weight, sex, and feedlot location are known exactly at the time the cattle are placed in a feedlot, the total number of days the cattle will be on feed is an estimate. However, days on feed usually varies by less than 14 days, so it is considered to be a conditioning variable for the purposes of this simulation.

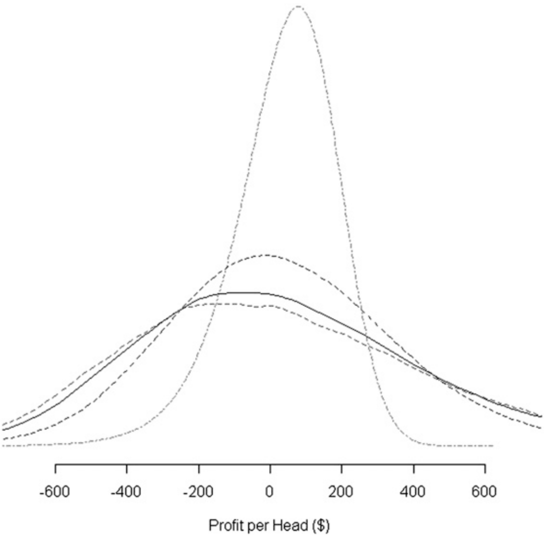

Figure 2. Conditional Profits per Head Distribution with Varying Levels of Live Cattle Price Volatility

and implied volatility has resulted in a wider distribution of profits for all volatility levels associated with fed cattle prices. The mean values of profit per head remained mostly unaffected by live cattle price variability. However, the standard deviation of profit was significantly increased. In this particular simulation, the high and low risk scenarios for live cattle prices changed the first quartile of profits by $96.10 per head. While profits per head rested just above $38 per head for each simulation, profit losses are highly probable.

The distribution associated with forward contracts shows the amount of risk that can be eliminated under this type of risk management strategy. However, it is also notable that the remaining variability is directly caused by variation in corn price and production. In light of the current situation for livestock producers, where prices are highly volatile, information regarding the distributional characteristics of profits under different scenarios is very important when making risk management decisions. Furthermore, understanding the amount of risk that remains in production allows producers to weigh the benefits of current risk management tools. In addition, we have identified conditioning variables that can be used to help reduce risk for cattle producers, which may be of particular interest to those who might be more risk averse.

An important component of this model is the assumption that yield factors are randomly determined, not fixed. To illustrate the importance of accounting for variability in yield factors, another set of simulations were run using various scenarios for average daily gain variability. In particular, a pen with similar characteristics to the one described above was compared with two pens that have different levels of *ADG*. Specifically, *ADG* was increased and decreased by one standard deviation, based on the estimated conditional mean of *ADG*. The results of these simulations are compared in Figure 3. Under this scenario both variance and mean profits change as the mean of *ADG* is increased. Profits increase from higher *ADG* because the pen is adding weight at a faster pace. Additionally, as *ADG* is increased, its variability plays a larger role in profit variability, making overall profits more widely distributed. Both of these factors account for the difference of $13.42 in the first quartile of profits between the high and low *ADG* simulations. Additionally, the mean of profits per head changed by $48.46 under the same scenarios as previously mentioned. This particular simulation brings to light the change in

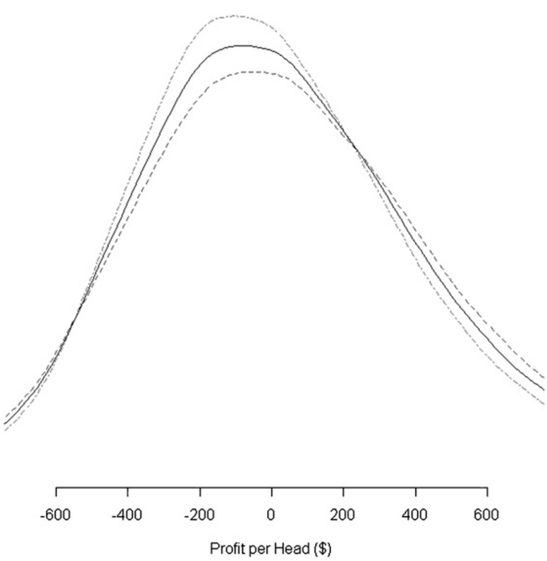

Figure 3. Conditional Profits per Head Distribution with Varying Levels of Mean ADG

profits that results from a pen of cattle with a higher ADG. More importantly, variables such as ADG have a significant impact on profits.

Conclusions

Developing efficient risk management strategies in fed cattle production requires careful consideration of the effects on profitability risk of not only input and output prices, but also cattle feeding yields. While other studies of cattle feeding profitability have used average daily gain and feed conversion as measures of yield, this study also explicitly considers the effects of overall cattle health on yield, using a comprehensive data set from cattle feedlots in Kansas and Nebraska.

Multiplicative heteroskedasticity models were estimated for each of the four yield measures; *DMFC*, *ADG*, *MORT*, and *VCPH*. Each model was constructed using conditioning variables, which reflect information known to a cattle feeder prior to placement of a pen of cattle on feed. The model estimates provide insight into the relative impact of the conditional variables on both the expected mean and variance of each measure of yield. This strategy for modeling cattle yields captures production variability by describing yield characteristics as conditional random variables, as opposed to using only an expected value for each. This allows us to model conditional profits by taking into account both risks arising from price and production variability.

Results of the *DMFC* model indicate statistically significant differences between gender, season, and feedlot location on feeding efficiency. Heavier weight cattle are less efficient at feed conversion than lighter weight cattle. In spite of this higher feed conversion, heavier weight placed pens gain more weight per day. Additionally, all conditioning variables significantly influence both the mean and variance of *ADG*. Pens with heavier placement weight tend to have fewer health problems and medication costs than pens placed at lighter weight.

Profit risk is impacted by fed cattle prices, feed costs, and yields. Therefore, to arrive at an *ex ante* estimate of the distribution of profits, the profit risk model must include all these sources of risk. Initial simulations using high and low variability in fed cattle prices indicate that fed cattle prices have a large impact on the overall variability of profit per head. Additionally, production factors such as *ADG* significantly alter the conditional mean and variability of profits.

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