VALUE OF SYSTEMATIC THORACIC ULTRASONOGRAPHY INFORMATION FOR DETECTING BOVINE RESPIRATORY DISEASE (BRD) RELATED LUNG DAMAGE IN CROSSBRED DAIRY CALVES

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Evan Long

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STATEMENT OF COMMITTEE APPROVAL

Dr. Nathanael Thompson, Chair
Department of Agricultural Economics

Dr. Nicole Widmar
Department of Agricultural Economics

Dr. Jacquelyn Boerman
Department of Animal Sciences

Approved by:
Dr. Nicole Widmar

Dedicated to my family and friends who have pushed me to where I am today.

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ABSTRACT

The purpose of this study is to evaluate the value of systematic thoracic ultrasonography (TUS) for detecting bovine respiratory disease (BRD) related lung damage in Holstein x Angus crossbred calves. Because the dairy industry is known to operate on small profit margins, it is important to assess the potential of this technology to help prevent the main source of financial loss related to calf production that dairy producers face. Studies have shown that BRD may impact nearly a fourth of all dairy calves before weaning. In an industry that is currently growing and evolving, it is important that producers have all the necessary resources to operate efficiently. TUS is known to be a quick and accurate predictor of BRD related lung damage, but this study focuses on the financial implications of BRD related lung damage on calf growth and efficiency—average daily gain (ADG) and milk-to-gain (M:G)—and the value of implementing TUS information to make sound management decisions. TUS along with BRD diagnosis information give producers a unique perspective on future growth and development of calves and could be part of the solution to promote larger profit margins for dairy producers. We find that the value associated with TUS and BRD diagnosis information is between $0.88/head and $13.44/head and depends on BRD incidence rate, feed price, and feeder price. Depending on the cost to the farm, it may be beneficial to implement this as a way to manage BRD damage, which we know to influence calf growth and efficiency.

CHAPTER 1. INTRODUCTION

The dairy industry is responsible for approximately 1% of U.S. Gross Domestic Product (GDP) and generates around 3 million jobs (Kaika, 2019). A recent study showed that the number of registered dairy herds in the U.S. has decreased by over half in the last 8 years due to the narrow profit margins faced by dairy producers (MacDonald et al., 2020). While many smaller farms show increased revenue per hundredweight, they have been unable to generate enough profit to cover expenses and are being forced to sell to larger farms who have lower production costs (MacDonald et al., 2007). With tight profit margins, it is necessary that dairy producers improve production efficiency to stay profitable. While the primary focus of dairy operations is milk production, feeder calf management and marketing provide an opportunity to improve profit margins.

With new strategies emerging to increase calf revenue, such as utilization of sexed semen, crossbreeding, and vaccinations, it is important that producers implement management practices that allow them to optimize net returns within their calf management system. Bovine respiratory disease (BRD) is an extremely important health issue in the dairy industry and is defined as, "a multifactorial disease resulting from a combination of calf, management, and pathogen factors (including bacteria and viruses)" (Buczinski et al., 2015, 228). A recent study shows that approximately 22% of all dairy calves in the United States will have BRD prior to weaning (Dubrovsky et al., 2020). Because BRD is estimated to impact two of every five dairy calves before they reach six months of age, without any measurement of the severity of the damage, BRD management is an integral part of any dairy calf management strategy (Stanton, 2009).

Extensive information is available on the topic of BRD in dairy calves, ranging from veterinary studies to analyses of the long-term effects on animal health, consumption, and productivity. Stanton (2009) suggests that BRD is known to cause economic hardship and damage to overall animal wellbeing. Because the cost of BRD has been studied comprehensively over the past 50 years, there is a great baseline for predicting current cost to producers. In 2020 approximately 35 million calves were born and studies have shown the average annual cost of BRD in the dairy herd to be approximately $21.44 per head (2020 U.S. Dollars) (Miller & Dorn, 1990; *USDA ERS - Dairy Data*, 2020; *USDA/NASS QuickStats Ad-Hoc Query Tool*, n.d.; Wallheimer, 2020). These figures imply that the United States dairy industry may have lost approximately 1.4 billion dollars to BRD in 2020 (*Cattle Inventory January 1, 2020 - Executive Briefing*, 2020; Miller & Dorn, 1990).

Many producers utilize preventative treatments to combat the negative effects of BRD. The simplest, yet most effective, preventative treatment for BRD is to increase milk consumption. Dubrovsky et al. (2020) report that increasing milk consumption was profitable in herds with more than 3% cumulative BRD incidence. Another common preventative treatment is administration of a live BRD vaccine to pregnant dams. This was also found to be profitable but only for farms experiencing high rates of BRD, making it less practical for many producers (Dubrovsky et al., 2020).

While preventative measures are effective in certain situations, they are not universally profitable and cannot solve the issue of BRD related losses for all producers (Dubrovsky et al. 2020). These preventative measures also require knowledge of previously existing BRD prevalence to be financially effective, which implies the need for a testing procedure to determine where preventative measures should be implemented (Dubrovsky et al. 2020). Data shows that many producers have not established a consistent, on farm, testing protocol for BRD (S. Buczinski et al., 2014; McGuirk & Peek, 2014). Much of the research on BRD is based on standardized scoring systems that evaluate symptoms from four major categories including rectal temperature, cough, nasal discharge, and ocular discharge (McGuirk and Peek 2014). These scoring systems would then be validated using a form of systematic thoracic ultrasound (TUS) (McGuirk and Peek 2014).

A recent study inspected veal calves at three different points in development (3 weeks after arrival, 13 weeks after and 2 weeks prior to slaughter) using a similar scoring system to the one described above that evaluated breathing, nasal discharge, and coughing (Leruste et al., 2012). After slaughter, lungs were inspected and assigned a score of 0-3 with 0 being healthy lungs and 3 being severely damaged lungs, to assess the accuracy of the scoring system when predicting lung lesions (Leruste et al. 2012). While this scoring system was found to be an accurate predictor of future health for calves with very damaged lungs, it was significantly less accurate when predicting the future health of calves who received lower lung scores post-mortem, leaving producers susceptible to ill-advised management decisions (Leruste et al. 2012).

It is clear that TUS can predict lung damage to some extent, but while many researchers are willing to use TUS as a test of accuracy, some still believe it is not yet reasonable to assume it could be used independently to test for BRD related lung damage (S. Buczinski et al., 2014; Sébastien Buczinski et al., 2015). A recent study was conducted to determine the accuracy and speed of preforming TUS on lung consolidation—caused by BRD—in dairy calves (S. Buczinski et al., 2013). The study was administered by technicians of varied experience and illustrates the potential of ultrasound technology to be utilized to diagnose BRD damage and reinforces the importance of BRD to not only dairy, but also beef calves. Buczinski et. al. (2013) focus on the benefits of using ultrasound technology to detect lung damage caused by BRD and suggests that TUS is the most efficient and accurate screening method available. It is unclear why TUS is typically utilized to evaluate the accuracy of less accurate testing procedures, and is not more commonly used as an independent testing procedure for BRD related lung scarring (S. Buczinski et al., 2013; Sébastien Buczinski et al., 2015; McGuirk & Peek, 2014).

A recent study was performed on 193 Holstein and 40 Jersey calves and tested the benefit of implementing TUS and a 6 level scoring system to classify lung consolidation (Cramer & Ollivett, 2019). The purpose of the study was to determine the specific lung consolidation score that would affect ADG. Each calf's clinical respiratory score (CRS) which is assigned based on an evaluation of each calf's nose, eyes, ears, cough, and rectal temperature was recorded and compared to TUS results (Cramer & Ollivett, 2019; McGuirk, 2008). They found that while CRS did explain some variation in ADG, TUS is quicker and more accurate when detecting lung damage caused by BRD due to, "superior sensitivity and specificity compared with CRS" (Sébastien Buczinski et al., 2015; Cramer & Ollivett, 2019). Another study on the effectiveness of different treatments for respiratory disease in dairy calves was unable to associate CRS with ADG (Heins et al., 2014). While Crammer and Ollivett (2019) found TUS to be beneficial, they also noted that the 6-level scoring system had too many classifications and would be a more accurate predictor with less categories.

The objective of this study is to evaluate the economic feasibility of TUS paired with a 3-level scoring system to predict the impact of bovine respiratory disease (BRD) on economic returns for dairy feeder calves. Such impacts include but are not limited to reduced consumption, decreased average daily gain (ADG), and increased mortality. The feasibility of TUS and the 3-level scoring system for predicting future performance will be examined and associated costs and benefits of implementing this information into the farm's management plan will be assessed for various levels of BRD incidence and input and output prices.

CHAPTER 2. CONCEPTUAL MODEL

Dairy producers are assumed to be profit maximizers in this study. For this reason, decision makers as assumed to be risk neutral. While the primary economic activity for dairy farms is milk production, an externality of pregnancies necessary to produce milk is calves. Historically, dairy calves have received less management attention than there milking counterparts, given their relatively low economic value – heifers calves were raised as replacements when necessary and bull/steer calves were sold. However, artificial insemination (including sexed semen), genomic predictions and embryo transfer technology have drastically changed the opportunities associated with dairy calf management/marketing, including manipulating sex outcomes to meet farm goals for replacements and opportunities to produce calves with beef genetics that are worth more as feeders than traditional dairy calves. In this study, we focus on the manager's decision to manage dairy calves in a way that will maximize net returns:

$$\max_{D_{ik}} E[NR_{ik}] = P_{feeder} \times SW_{ik}(BW, ADG_{ik}, D_{ik}) \times (1 - MR)$$
$$- \left[MC_{ik} \times P_{milk} + FC_{ik} \times P_{feed} \times (D_{ik} - 60) + OC_{ik} + \delta \times T\right]$$

where the decision maker chooses D_{ik}, the age in days at which calves are sold, k is BRD diagnosis and i is the lung score determined by TUS. P_{feeder} is feeder cattle price at sale ($/lb.), SW_{ik} is sale weight (lbs.), BW_{ik} is birth weight (lb.), ADG_{ik} is average daily gain (lb./day), MR is mortality rate (%), MC_{ik} is milk consumption from birth to weaning (l.), P_{milk} is milk price ($/l.), FC_{ik} is feed consumption from weaning until the calf is sold (lb./day), P_{feed} is feed price ($/lb.), OC_{ik} is opportunity cost of feed, milk, and keeping the calf ($), δ is the proportion of the herd that is treated for BRD (%), and T is BRD related treatment cost ($/calf).

At birth, birth weight is the only dependent variable known with certainty. Future performance, and thus revenue and costs, are unknown and likely to be influenced by animal health. Decision makers have the opportunity to obtain additional information about calf health by tracking BRD diagnoses and conducting TUS to identify lung damage based on lung consolidation. This information can be used to predict future calf performance and therefore manage animals differentially to maximize net returns. Although acquiring this BRD diagnosis and lung score information may be beneficial in terms of calf management, it also incurs a cost to the farm. Following Stigler (1961), the value of information is determined by maximizing net returns in the absence of BRD diagnosis and lung score information and then maximizing net returns with this information. The difference in expected net returns is the value of information.

CHAPTER 3. DATA

Data were collected for 412 calves at various stages in development from a commercial dairy farm in Indiana. Of these calves, 235 are purebred Holstein (H) and 177 are Holstein x Angus crossbred calves (F1). Recorded characteristics include date of birth, birth weight, gender, TUS score, number of times contracting BRD, weaning weight, total milk consumption up to weaning, and a comprehensive list of medications and applications for BRD treatments.

Bias was reduced by taking weights at strategic points in calf development to promote consistency. Calculations were then made to develop an understanding of individual calf development, so that analysis could be conducted on what kind of impact BRD has on calf weight gain per liter of milk consumed. Automated feeders were used to track the exact consumption and number of days on milk of each calf through early development. Certain observations were made based off specific milestones in calf development such as weaning weight, days on an automated feeder, milk consumption, and amount of milk per pound of weight gain. Some observations were made on specific dates to limit variability and human error and these observations included individual lung score and analysis lung score. It is important to note that all observations related to TUS were performed by the same person to limit variability in the interpretation of lung scaring and the analysis present in overall lung score.

The scoring system assigns each calf a numerical value based on BRD related consolidation present in their lungs. If there is no significant damage to either lung then the calf is assigned a 0. If there is significant damage to one lung, they receive a 1 and if there is significant damage to both lungs, a score of 2 is assigned. Scores are assigned based on analysis of TUS performed approximately one week prior to weaning. BRD diagnoses—whether a calf has been diagnosed with BRD at least once in its lifetime—will be evaluated as a substitute and complimentary method of evaluating likelihood of financial loss due to reduced weight gained per pound of feed consumed (Milk-to-gain).

Of the 412 calves enrolled in this study, 59% showed no BRD related lung consolidation and were assigned lung score 0, 22% had consolidation in one lung and were assigned lung score 1 and 19% had lung consolidation in both and were assigned a lung score of 2. Of the calves in the study, 86% of calves had one or more documented BRD diagnoses and 14% had no reported BRD diagnoses.

Mortality from bovine respiratory disease (BRD) in dairy calves is approximately 1% through weaning and then 3% until 120 days (Callan & Garry, 2002). A 7% annual interest rate was assumed and divided by twelve to determine monthly interest of 0.58%. We utilized this interest rate to calculate the opportunity cost of buying milk and feed.

Feed and milk costs are based off university farm budgets and will be evaluated at multiple price points. Feed costs are assumed to be between \$0.10/lb. and \$0.20/lb with the most likely feed cost being \$0.15/lb. for dry matter (Christensen, 2020). Due to the partial budgeting approach and lack of data on pre-weaning feed costs, feed consumption before weaning will not be considered in the model. Market price for Holstein x Angus crossbred calves will also be evaluated at multiple price points and is assumed to be between \$56/cwt. and \$167/cwt. with the most likely value being \$111/cwt. Feed needs after weaning are based on average needs among calves with the same score and were calculated with the following formula:

$$Cons_{feed_{i,k}} = 12 \times \left(\frac{Gain_{baseline}}{Gain_{ik}}\right)$$

where subscript i is lung score and subscript k is BRD diagnoses, $Gain_{baseline}$ is the consumption required to gain 1 lb. of body weight, for calves without lung consolidation, prior to weaning (lt./kg.) and Gain is the consumption required to gain 1 lb. of body weight, for calves of a given lung score (lt./kg.). This calculation gives a ratio of each lung score's average ability to convert feed to body weight. This ratio is then be multiplied by the base quantity of feed, which is assumed to be 12 lb./day for a calf that weighs between 300 lb. and 500 lb. (Grant & Mader, n.d.).

Average BRD treatment costs were assumed to be \$15.05/head for all calves diagnosed with BRD at least once (Dubrovsky et al., 2020). This assumption is based off a recent study that analyzed data on 11,470 calves across 5 different dairy farms with unique management practices and detailed records (Dubrovsky et al., 2019). 22.7% of the calves in the study were diagnosed with BRD at least once (Dubrovsky et al., 2020).

CHAPTER 4. METHODS AND PROCEDURES

4.1 Statistical Analysis

Analysis of variance (ANOVA) was performed using PROC MIXED in SAS 9.4 (SAS Institute, 2016). Dependent variables include birth weight (BW), ADG, and milk-to-gain ratio (M:G). BRD diagnosis, lung score, and their interaction were included as fixed effects. Gender and breed fixed effects were also included. Interactions between gender and breed with BRD diagnosis and lung score were explored but were not statistically significant. Therefore, they were not included in the final model. Homogeneity of variance and normality assumptions of the ANOVA model were tested. Violations of homoskedasticity and normality are corrected using the EMPIRICAL statement to estimate standard errors that are robust to heteroskedasticity and non-normality (SAS Institute, 2016).

4.2 Economic Simulation

This study evaluates six scenarios that represent different management decisions that can be made from the given information. Each scenario is analyzed via Monte Carlo simulation in @Risk (Palisade Technology Solutions Corp., Ithaca, NY.). Each scenario was simulated once with 5,000 iterations. These stylized scenarios represent the decision makers profit maximizing choice for how long to keep these calves in the herd under various assumptions about BRD diagnosis and TUS information. Comparing net returns among scenarios with and without information allows us to estimate the value of information (Stigler, 1961). In other words, the value of information is an estimate of how much a decision maker could pay to collect BRD diagnosis and/or TUS information.

A partial budgeting approach is used to examine net returns focusing only on those costs and returns affected by BRD diagnosis and lung score information. Costs of calf development are based on current market prices. Development costs include feed cost, milk replacer, and treatment cost (Table 4.1). Feeder cattle price is based on current market price. Minimum and maximum feeder price values are set 50% above and below the most likely value to cover a broad range of price possibilities.

Table 4.1. Parameter values for Monte Carlo simulation of net returns to calf production.

Variable	Unit	Deterministic Value	Parameters for triangular distributions of variables. Minimum	Most Likely	Maximum
Distributions based on informed assumptions					
Feeder Price	$/lb.		0.56	1.11	1.67
Feed Cost	$/lb.		0.10	0.15	0.20
Milk Replacer	$/lt.	0.24			
Secondary Data					
Annual Interest	%	7			
BRD Mortality					
90 Days	%	1			
120 Days	%	3			
Treatment Cost	$/calf	15.05			
Baseline Feed Consumption	Lbs./day	12			

The correlation between feed cost and feeder cattle price was evaluated, but no strong relationship was found. Because it takes up to 18 months for calves to reach market condition, it makes sense that feeder cattle price would be relatively inelastic to changes in feed prices in the short run. Since this study only covers 120 days, it is reasonable to assume that there is no direct impact of feed cost on feeder cattle price.

4.2.1 Scenario #1

In scenario #1 all calves are sold at weaning (60 days). This will serve as a baseline and will ignore all the information provided by BRD diagnosis and lung score information. In this scenario, there is milk cost and opportunity cost on milk, but there will be no additional dry feed cost or opportunity cost on feed because all calves will be sold at weaning. The mortality rate for this scenario is 1% and will be applied to all calves. Net returns are calculated as:

$$NR_{scenario1} = (BW + ADG \times 60) \times P_{feeder} \times (1 - Mort) - Cons_{milk} \times P_{milk} - OppCost_{milk} - \delta \times T$$

where BW is birth weight (lbs.), ADG is average daily gain (lbs./day), P_{feeder} is market price for feeder calves ($/lb.), Mort is mortality rate (%), $Cons_{milk}$ is milk consumption in the first 60 days (lt.), P_{milk} is price of milk ($/lt.), $OppCost_{milk}$ is the opportunity cost of feeding milk ($), δ is the proportion of the herd that is treated for BRD (%), and T is BRD related treatment cost ($/calf).

4.2.2 Scenario #2

In scenario #2 all calves are fed to 120 days and sold at market price. This scenario serves as an alternative baseline scenario (in addition to Scenario #1) because it also ignores the information provided by BRD diagnosis and lung score information. The mortality rate is 3% and will be applied to all calves. Net returns are calculated as:

$$NR_{scenario2} = (BW + ADG \times 120) \times P_{feeder} \times (1 - Mort) - Cons_{milk} \times P_{milk} \\ - Cons_{feed} \times 60 \times P_{feed} - OppCost_{milk} - OppCost_{feed} - \delta \times T$$

where BW is birth weight (lbs.), ADG is average daily gain (lbs./day), P_{feeder} is market price for feeder calves ($/lb.), Mort is mortality rate (%), $Cons_{milk}$ is milk consumption in the first 60 days (lt.), P_{milk} is price of milk ($/lt.), $Cons_{feed}$ is daily feed consumption after weaning (lbs./day), P_{feed} is the price of dry feed ($/lb.), $OppCost_{milk}$ is the opportunity cost of feeding milk ($), $OppCost_{feed}$ is the opportunity cost of feeding dry feed after weaning, δ is the proportion of the herd that is treated for BRD (%), and T is BRD related treatment cost ($/calf).

4.2.3 Scenario #3

In scenario #3, all calves are scanned and calves with a lung score of 2 are sold at weaning (60 days). Calves receiving a lung score of 0 or 1 are kept and sold at 120 days. When comparing this scenario to scenario #1 and scenario #2 we can calculate the value of information associated with TUS paired with the given lung consolidation scoring system. This scenario does not consider the information we are given in BRD diagnosis, but we will evaluate that in later scenarios. Net returns are calculated as:

$$NR_{scenario3} = \lambda \times \left[\left(BW + ADG_{0,1} \times 120\right) \times P_{feeder} \times (1 - Mort) - Cons_{milk0,1} \times P_{milk} - Cons_{feed0,1} \times 60 \times P_{feed} - OppCost_{milk0,1} - OppCost_{feed0,1} - \delta \times T\right] + (1 - \lambda) \times \left[(BW + ADG_2 \times 60) \times P_{feeder} \times (1 - Mort) - Cons_{milk2} \times P_{milk} - OppCost_{milk2} - \delta \times T\right]$$

where 0,1,2 subscripts are lung score, λ is the proportion of calves that are lung score 0 or 1, BW is birth weight (lbs.), ADG is average daily gain (lbs./day), P_{feeder} is market price for feeder calves ($/lb.), Mort is mortality rate (%), $Cons_{milk}$ is milk consumption in the first 60 days (lt.), P_{milk} is price of milk ($/lt.), $Cons_{feed}$ is daily feed consumption after weaning (lbs./day), P_{feed} is the price of dry feed ($/lb.), $OppCost_{milk}$ is the opportunity cost of feeding milk ($), $OppCost_{feed}$ is the opportunity cost of feeding dry feed after weaning, δ is the proportion of the herd that is treated for BRD (%), and T is BRD related treatment cost ($/calf).

4.2.4 Scenario #4

In scenario #4, calves are evaluated by BRD diagnosis. This scenario serves as a baseline for determining the value of information that is related to BRD diagnosis information. If an animal has had one or more positive BRD diagnoses (BRD diagnoses > 0), they are sold at weaning (60 days) and if they have no documented BRD diagnoses (BRD diagnoses = 0) they are kept until 120 days. This scenario ignores lung score information, but when compared to scenario #1 and scenario #2 gives us the value of information of knowing if a calf has been diagnosed with BRD. Net returns are calculated as:

$$NR_{scenario4} = (1 - \delta) \times \left[(BW + ADG^0 \times 120) \times P_{feeder} \times (1 - Mort) - Cons^0_{milk} \times P_{milk} - Cons^0_{feed} \times 60 \times P_{feed} - OppCost^0_{milk} - OppCost^0_{feed}\right] + \delta \times \left[\left(BW + ADG^{\emptyset} \times 60\right) \times P_{feeder} \times (1 - Mort) - Cons^{\emptyset}_{milk} \times P_{milk} - OppCost^{\emptyset}_{milk} - T\right]$$

where 0, $\emptyset$ superscripts are BRD diagnosis, δ is the proportion of the herd that is treated for BRD (%), BW is birth weight (lbs.), ADG is average daily gain (lbs./day), P_{feeder} is market price for feeder calves ($/lb.), Mort is mortality rate (%), $Cons_{milk}$ is milk consumption in the first 60 days (lt.), P_{milk} is price of milk ($/lt.), $Cons_{feed}$ is daily feed consumption after weaning (lbs./day), P_{feed} is the price of dry feed ($/lb.), $OppCost_{milk}$ is the opportunity cost of feeding milk ($), $OppCost_{feed}$ is the opportunity cost of feeding dry feed after weaning, and T is BRD related treatment cost ($/calf).

4.2.5 Scenario #5

In this scenario, calves will first be separated based off whether they have had one or more positive BRD diagnoses. All calves with no documented BRD diagnoses will be kept until 120 days. All calves that had one or more documented BRD diagnoses will be scanned and calves with a score of 2 will be sold at weaning (60 days), while calves with a score of 0 or 1 will be kept and sold at 120 days. This scenario incorporates both lung score and BRD diagnosis information. Net returns are calculated as:

$$
\begin{aligned}
NR_{scenario5} = {} & (1-\delta) \\
& \times \left[(BW + ADG^{0} \times 120) \times P_{feeder} \times (1 - Mort) - Cons_{milk}^{0} \times P_{milk} \right. \\
& \left. - Cons_{feed}^{0} \times 60 \times P_{feed} - OppCost_{milk}^{0} - OppCost_{feed}^{0} \right] \\
& + \delta \\
& \times \left\{ \lambda \right. \\
& \times \left[\left(BW + ADG_{0,1}^{\emptyset} \times 120\right) \times P_{feeder} \times (1 - Mort) - Cons_{milk0,1}^{\emptyset} \times P_{milk} \right. \\
& \left. - Cons_{feed0,1}^{\emptyset} \times 60 \times P_{feed} - OppCost_{milk0,1}^{\emptyset} - OppCost_{feed0,1}^{\emptyset} \right] \\
& + (1-\lambda) \\
& \times \left[\left(BW + ADG_{2}^{\emptyset} \times 60\right) \times P_{feeder} \times (1 - Mort) - Cons_{milk2}^{\emptyset} \times P_{milk} \right. \\
& \left. \left. - OppCost_{milk2}^{\emptyset} \right] - T \right\}
\end{aligned}
$$

where 0,1,2 subscripts are lung score and 0, $\emptyset$ superscripts are BRD diagnosis, δ is the proportion of the herd that is treated for BRD (%), λ is the proportion of calves that are lung score 0 or 1, ADG is average daily gain (lbs./day), P_{feeder} is market price for feeder calves ($/lb.), Mort is mortality rate (%), $Cons_{milk}$ is milk consumption in the first 60 days (lt.), P_{milk} is price of milk ($/lt.), $Cons_{feed}$ is daily feed consumption after weaning (lbs./day), P_{feed} is the price of dry feed

(\$/lb.), $OppCost_{milk}$ is the opportunity cost of feeding milk (\$), $OppCost_{feed}$ is the opportunity cost of feeding dry feed after weaning, and T is BRD related treatment cost (\$/calf).

Once distributions for all five scenarios are obtained, the profit maximizing scenario will be determined. In addition, the difference in net return values represent the value of BRD diagnosis and TUS information. Scenarios #3-5 will be compared to both scenario #1 and #2 to evaluate the value of information for two different types of producers, those who sell all at weaning and those who prefer to feed after weaning. Scenario #3 will be compared to baseline scenario #1 and baseline scenario #2 to give us the value of information associated with TUS. This value of information will show whether TUS and the associated scoring system increases net return or not. Next, we will compare scenario #4 to baseline scenario #1 and baseline scenario #2 which will give us the value of information of tracking whether each calf calves has had one or more documented BRD diagnoses. This determines if there is an economic benefit to keeping track of and sorting calves based off their history with BRD.

Finally, scenario #5 is compared with scenario #1 and scenario #2 to determine the value of information of TUS with BRD diagnosis information, then scenario #5 is compared to scenario #4 to find the value of information associated with scanning calves in addition to BRD diagnoses information. We expect this to be the most profitable scenario because it accounts for potential misdiagnosis of the severity of lung damage in calves with no documented BRD diagnoses by keeping all such calves until 120 days regardless of their lung score. This scenario also provides a more in-depth analysis of calves that had one or more documented BRD diagnoses than scenario #4, because rather than selling all calves at 60 days, they are scanned and the calves without damage to both lungs are kept until 120 days.

CHAPTER 5. RESULTS

5.1 Analysis of Variance

5.1.1 Birthweight

At the 5% significance level, a significant gender effect was identified in dairy calf birthweight (BW) ANOVA model (Table 5.1). Lung score (S), BRD diagnosis (D) and S × D interaction did not significantly influence BW at the 5% level. This was expected given these factors should have no impact on prenatal development. No significant breed interaction was found in the BW ANOVA model.

5.1.2 Average Daily Gain

At the 5% significance level a significant D × S interaction was identified in ADG ANOVA model, indicating that the impact of lung score on ADG depends on whether a calf has been diagnosed with BRD (Table 5.1). There were also significant gender and breed effects identified in ADG ANOVA model at the 5% significance level.

Table 5.2 categorizes mean ADG for calves of lung score 0, 1, and 2, with and without a previous BRD diagnosis. There was no significant difference in mean ADG for calves that had not been diagnosed with BRD. This is consistent with the producer's decision in scenario #4 where all calves who had not been diagnosed were kept, regardless of lung score. Among calves with at least one previous BRD diagnoses, 2's have a significantly lower mean ADG than 0's and 1's at the 5% significance level. Because the differences in ADG were significant for calves of different lung scores that had been diagnosed for BRD at least once, it is important to have a scenario that implements both lung score information and BRD diagnoses, such as scenario #5.

5.1.3 Milk-to-gain Ratio

BRD diagnosis (D) and lung score (S) both significantly influenced milk-to-gain ratio (M:G) (Table 5.1). The D × S interaction, gender, and breed effects were not statistically significant in the M:G ANOVA model.

Table 5.1. Analysis of variance for lung score, BRD diagnosis, lung score times BRD diagnosis, gender and breed on birth weight, average daily gain, and milk-to-gain ratio.

Source of Variation	*df*	*BW*	*df*	*ADG*	*df*	*M:G*
BRD Diagnosis (D)	1	ns[a]	2	**	2	***
Lung Score (S)	2	ns[a]	1	***	1	*
D × S	2	ns[a]	2	**	2	ns[a]
Gender	1	***	1	**	1	ns[a]
Breed	1	ns[a]	1	***	1	ns[a]

*** Significant at the 0.01 probability level.
** Significant at the 0.05 probability level.
* Significant at the 0.1 probability level.
a Not statistically Significant.

Table 5.2. Mean ADG values and differences in least square means.

Lung Score	*No BRD Diagnoses*	*At least one Diagnosis*
0	1.98a (0.061)	1.93a (0.04)
1	1.99a (0.062)	1.74b (0.048)
2	1.93a (0.169)	1.54c (0.058)

Means followed by the same letter are not significantly different at the 5% level.

Table 5.3 categorizes mean M:G for calves of lung score 0, 1, and 2, with and without a previous BRD diagnosis. Mean M:G for calves with no previous BRD diagnoses is not significantly different for any lung score at the 5% level. Similarly, at the 5% significance level there is no significant difference in mean M:G for calves that have been diagnosed with BRD at least once and have a lung score of 0 or 1 and calves without a previous BRD diagnoses with any score. At the 5% significance level, calves that have previously been diagnosed with BRD with a lung score of 2 were found to have a significantly higher mean M:G than claves with no previous BRD diagnosis and calves with at least on previous BRD diagnoses with lung score 0 or 1.

Table 5.3. Mean M:G values and differences in least square means.

Lung Score	*No BRD Diagnoses*	*At least one Diagnosis*
0	8.21a (0.404)	8.30a (0.223)
1	8.49a (0.773)	9.00a (0.301)
2	9.01a (0.922)	10.68b (0.329)

Means followed by the same letter are not significantly different at the 5% level.

5.2 Economic Simulation

Because of the significant breed effects in the ADG ANOVA model, separate simulations for Holsteins and Holstein x Angus crossbred calves are needed to properly account for differences in calf outcomes. We focus our discussion primarily on the simulation for Holstein x Angus crossbred calves since they are bred and managed specifically to be sold as feeder calves. The 235 purebred Holstein calves included in this study are all heifers which could be sold as feeder cattle, but more typically would be raised for the purpose of entering the milking herd. However, we do not have enough data to establish the costs and benefits of BRD diagnoses or lung score information on milk production. Therefore, feeder cattle scenarios are replicated for the purebred Holstein heifers to determine the robustness of our results to breed effects.

5.2.1 Holstein x Angus Cross

The initial simulation is run with the BRD incidence rate observed in the data (85%). Scenario #1 describes producers that would typically sell calves at weaning and had a mean return of $99.07/head with minimum and maximum values of -$13.28/head and $208.51/head (Table 5.4). Scenario #2 describes producers who would typically sell calves at 120 days and had a slightly lower average return at $97.97/head but was much more volatile with results ranging from -$91.37/head to $289.04/head and a standard deviation of $71.16/head versus $45.34/head in scenario #1. Like many investments, the longer the dairy owns the calves, the more risk they are exposed to due to changing growth patterns, health issues, and potential death.

Scenario #3 implements TUS with a scoring system to identify the extent of lung damage associated with BRD. The mean return for this scenario is $105.03/head and ranged from -$68.82/head to $281.05/head with a standard deviation of $66.75/head (Table 5.4). Comparing these values with the net returns in scenarios #1 and #2 indicates that the value of lung score information to manage calves is $5.95/head on average for producers that would otherwise sell calves at weaning and $7.06/head for producers that would otherwise feed them to 120 days (Table 5.5). In other words, producers could pay, on average, up to $7.06/head to for TUS, including labor and equipment costs.

Scenario #4 implements BRD diagnoses information into calf management decisions. Scenario #4 had a mean net return of $101.21/head and ranged from -$18.56/head to $219.35/head (Table 5.4). The value of information associated with making management decisions for the entire herd based solely on BRD diagnoses has a mean of $2.14/head for producers who would normally sell calves at weaning and $3.24/head for producers that sell calves at 120 days (Table 5.5).

Scenario #5 implemented both TUS and BRD diagnosis information into calf management decisions. Scenario #5 had the highest average return at $105.07/head and ranged from -$70.43/head to $282.95/head (Table 5.4). The value of information associated with scanning animals in this scenario is $6.00/head for producers that would otherwise sell calves at weaning and $7.10/head for producers that would have kept them to sell at 120 days (Table 5.5). Notice that the TUS and BRD diagnosis information is sub-additive. This is not surprising given the expected correlation between TUS and BRD diagnoses information.

When compared to scenario #4, the additional value of information associated with TUS on calves that have one or more documented BRD diagnoses is $3.86/head (Table 5.5). This value is the same regardless of if you compare to scenario #1 or scenario #2, given that it represents the value of TUS information in addition to BRD diagnoses information which is indifferent to the "baseline." Notice that the value of TUS information in the presence of BRD diagnosis is nearly half of the value of information when BRD diagnosis information was absent (scenario #3). Hence, the economic feasibility of collecting TUS information is diminished for farms that already collect and utilize BRD diagnosis information.

Table 5.4. Descriptive statistics for @Risk projected outcomes of all five scenarios for crossbred calves with 85% incidence rate.

	Min	Max	Mean	SD
Scenario #1	$ (13.28)	$ 208.51	$ 99.07	$ 45.34
Scenario #2	$ (91.37)	$ 289.04	$ 97.97	$ 71.16
Scenario #3	$ (68.82)	$ 281.05	$ 105.03	$ 66.75
Scenario #4	$ (18.56)	$ 219.35	$ 101.21	$ 49.28
Scenario #5	$ (70.43)	$ 282.95	$ 105.07	$ 67.24

Table 5.5. Value of information associated with each scenario and the potential baseline management strategies for Holstein x Angus crossbred calves with an 85% BRD incidence rate.

	Scenario #1 – All calves sold at weaning	**Scenario #2** – All calves sold at 120 days
Scenario #3 – 2's are sold at weaning and 0's and 1's are kept until 120 days	$5.95 (23.79)	$7.06 (5.20)
Scenario #4 – Calves that have been diagnosed with BRD at least once are sold at weaning and calves with no previous diagnoses are kept until 120 days.	$2.14 (4.52)	$3.24 (24.39)
Scenario #5 – Calves that have not been previously diagnosed with BRD are kept until 120 days. Calves that have been diagnosed with BRD are scanned and 2's are sold at 90 days but 0's and 1's kept until 120 days.	$6.00 (24.31)	$7.10 (4.68)
Difference in Scenario #5 and Scenario #4	$3.86 (19.87)	$3.86 (19.87)

Sensitivity Analysis

The tornado plot in Figure 5.1 shows the impact of different variables on the value of information for scenario #5. Scenario #5 was chosen here because it has the highest value of information, but the results of the sensitivity analyses for the other scenarios were qualitatively similar. The value of TUS and BRD diagnosis information is most sensitive to changes in the feeder calf price. A high feeder calf price results in increased value of information for scenarios that keep more calves to 120 days and a low feeder calf prices result in a higher value of information for scenarios that sell more calves at weaning. The bars in Figure 4.1 represent the range of the values of information that result from changes in individual input variables.

Another variable that contributes to changes in value of information is feed price. When feed prices are high it is better for producers to sell calves sooner, therefore the value of information of scenarios that sell more calves at weaning increases. When input prices are lower, producers profit more from feeding calves as long as possible and that causes the value of information to increase for strategies that keep more calves until 120 days. While input values such as M:G and ADG also impact value of information, they are far less impactful than feeder calf price and feed price (Figure 5.1).

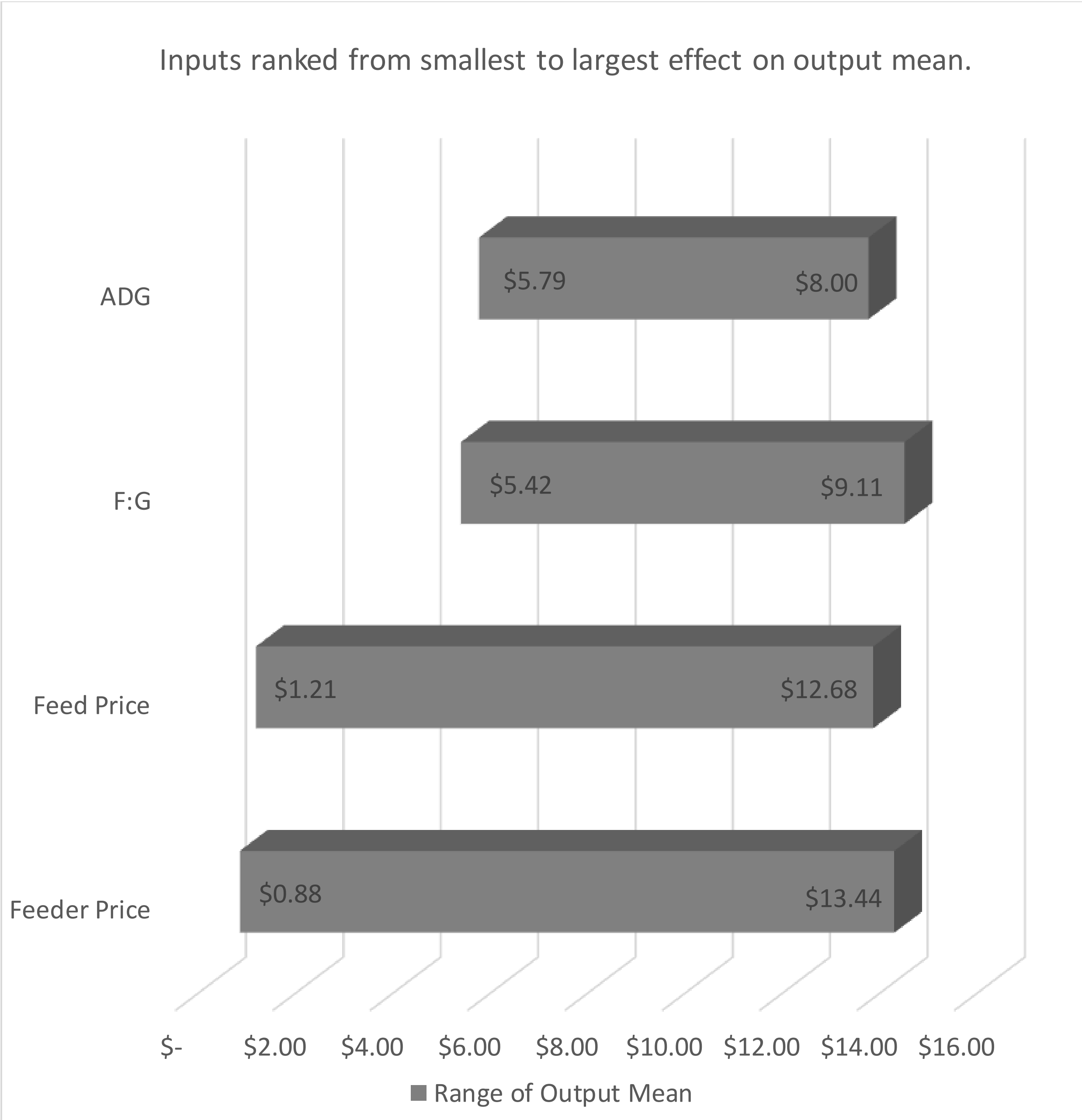

Figure 5.1. Tornado plot for change in output value of information for Holstein x Angus crossbred calf scenario #5 when compared to baseline scenario #2 at an 85% BRD incidence rate.

5.2.2 Lower BRD Incidence Rates

The high BRD incidence observed in the data will certainly influence the values of information associated with BRD and TUS information. Therefore, to determine the sensitivity of these values to this assumption, the simulation is re-run with lower BRD incidence rate.

Expected values of information for TUS and BRD diagnoses information for Holstein x Angus crossbred calves, with a 50% BRD incidence rate are found in Table 5.6. The value of information associated with TUS information is $9.17/calf for producers who would typically sell calves at weaning and $4.05/calf for producers who would typically sell all calves at 120 days (Table 5.6). The value of information associated with BRD diagnoses information is $7.04/calf for producers that would sell at weaning and $1.92/calf for producers that would otherwise sell at 120 days. The value of information of utilizing both BRD and lung scan information is $9.31/head for producers who would typically sell at weaning and $4.19/calf for producers who prefer to sell at 120 days. When compared to scenario #4, the difference in value of information associated with scanning calves who have been diagnosed with BRD at least once is $2.27 for both producers who prefer to sell at weaning and producers who prefer to sell at 120 days. The scenario with the highest net return is still scenario #5, so it makes sense to scan only animals that have been diagnosed with BRD at least once. Because BRD diagnosis had a significant interaction with ADG, this information utilized in tandem with lung score information provides the highest net return on average.

Table 5.6. Value of information associated with each scenario and the potential baseline management strategies for Holstein x Angus crossbred calves with a 50% BRD incidence rate.

	Scenario #1 – All calves sold at weaning	**Scenario #2** – All calves sold at 120 days
Scenario #3 – 2's are sold at weaning and 0's and 1's are kept until 120 days	$9.17 (25.02)	$4.05 (4.62)
Scenario #4 – Calves that have been diagnosed with BRD at least once are sold at weaning and calves with no previous diagnoses are kept until 120 days.	$7.04 (15.06)	$1.92 (14.56)
Scenario #5 – Calves that have not been previously diagnosed with BRD are kept until 120 days. Calves that have been diagnosed with BRD are scanned and 2's are sold at 90 days but 0's and 1's kept until 120 days.	$9.31 (26.77)	$4.19 (2.80)
Difference in Scenario #5 and Scenario #4	$2.27 (11.85)	$2.27 (11.85)

With a lower BRD incidence rate, it is not surprising that the average value of information of knowing TUS and BRD diagnosis information becomes more beneficial to producers who would typically sell calves at weaning. A lower BRD incidence rate means that there are more healthy calves, which the above scenarios have shown to be profitable to keep until 120 days. If the producer plans to sell all calves at weaning, then TUS and BRD diagnoses information could help them to identify healthy calves and increase overall net return. On the other hand, producers who would typically sell all calves at 120 days see decreasing average value of information of TUS and BRD diagnoses information as BRD incidence rate decreases. Because these producers already plan to keep calves to 120 days, fewer sick calves means that there is a lower average value of knowing which ones to sell at weaning.

Reducing the BRD incidence rate to 15% has the same general effect on the value of information (Table 5.7). Producers who tend to follow the management strategy in scenario #1 see higher values of information, because they have more healthy animals (as much as $13/head), and producers following the strategy in scenario #2 see decreasingly lower values of information as they have fewer and fewer sick calves.

Table 5.7. Value of information associated with each scenario and the potential baseline management strategies for Holstein x Angus crossbred calves with a 15% BRD incidence rate.

	Scenario #1 – All calves sold at weaning	**Scenario #2** – All calves sold at 120 days
Scenario #3 – 2's are sold at weaning and 0's and 1's are kept until 120 days	$12.42 (26.15)	$1.02 (4.10)
Scenario #4 – Calves that have been diagnosed with BRD at least once are sold at weaning and calves with no previous diagnoses are kept until 120 days.	$11.98 (25.61)	$0.57 (4.36)
Scenario #5 – Calves that have not been previously diagnosed with BRD are kept until 120 days. Calves that have been diagnosed with BRD are scanned and 2's are sold at 90 days but 0's and 1's kept until 120 days.	$12.66 (29.10)	$1.26 (0.84)
Difference in Scenario #5 and Scenario #4	$0.68 (3.55)	$0.68 (3.55)

5.2.3 Holsteins

Expected net returns for scenarios #1-#5 for Holsteins are reported in Table 5.8. When compared to scenario #1, there is a negative value of information associated with BRD diagnosis and TUS information (Table 5.9). While TUS and BRD diagnoses information still give health insights, it reflects a negative value of information because marginal returns after weaning tend to be negative. Because purebred Holsteins have lower ADG, they do not gain weight efficiently as crossbred calves. Therefore, there tends to be less opportunity to raise them as profitable feeder cattle even in the presence of TUS and BRD diagnosis information.

For a producer that typically keeps calves to 120 days, the value of information associated with knowing lung score information is \$9.49/head (Table 5.9). The scenario with the highest value of information is scenario #4. The average value of information of knowing BRD diagnosis information is \$15.00/head. The value of information associated with BRD diagnoses and TUS information combined is \$9.13/head. For a producer that prefers to keep calves until 120 days, the value of information of TUS and BRD diagnosis is especially high. This is because, at current market prices, marginal cost is higher than marginal revenue after weaning. Therefore, any information that prompts the producer to sell more purebred Holstein heifers at weaning will add value to TUS and BRD diagnosis information.

Table 5.8. Descriptive statistics for @Risk projected outcomes of all five scenarios for Holsteins.

	Min	Max	Mean	SD
Scenario #1	\$ (31.73)	\$ 220.48	\$ 89.26	\$ 44.45
Scenario #2	\$ (142.08)	\$ 318.52	\$ 73.95	\$ 71.09
Scenario #3	\$ (116.11)	\$ 312.38	\$ 83.45	\$ 67.37
Scenario #4	\$ (38.72)	\$ 230.39	\$ 88.99	\$ 48.03
Scenario #5	\$ (116.50)	\$ 312.59	\$ 83.09	\$ 67.70

Table 5.9. Value of information associated with each scenario and the potential baseline management strategies for purebred Holsteins.

	Scenario #1 – All calves sold at weaning	**Scenario #2** – All calves sold at 120 days
Scenario #3 – 2's are sold at weaning and 0's and 1's are kept until 120 days	-$5.80 (27.49)	$9.49 (8.19)
Scenario #4 – Calves that have been diagnosed with BRD at least once are sold at weaning and calves with no previous diagnoses are kept until 120 days.	-$0.28 (5.81)	$15.00 (28.14)
Scenario #5 – Calves that have not been previously diagnosed with BRD are kept until 120 days. Calves that have been diagnosed with BRD are scanned and 2's are sold at 90 days but 0's and 1's kept until 120 days.	-$6.15 (27.80)	$9.13 (7.96)
Difference in Scenario #5 and Scenario #4	-$5.88 (24.19)	-$5.89 (24.19)

CHAPTER 6. CONCLUSION

There is value associated with implementing TUS to identify BRD related lung consolidation in Holstein x Angus crossbred calves. In the case of a high BRD incidence rate the value of information is similar for both producers who typically sell at weaning and producers who prefer to keep calves to 120 days. As the BRD incidence rate decreases, producers who would normally keep calves longer see lower average values of information obtained from TUS while producers who would normally sell calves sooner see higher average values of information from TUS. This makes sense because herds with lower BRD incidence rates would have more healthy calves and any information that motivates producers to keep them longer will increase returns. Producers who prefer to sell calves at weaning gain more value from TUS the lower the incidence rate because TUS information causes them to keep healthy animals that they would otherwise sell.

This study does not find purebred Holstein heifers to have positive marginal returns after weaning at current market feeder calf price and feed price. The best strategy is to sell them at as quickly as possible if they are not going to be kept as replacements for the milking herd. However, for producers who would prefer to keep them, there may be value in TUS information. We do not have data to determine the value of information associated with using TUS to predict future milk production. There is evidence to show that BRD significantly impacts milk production, so if TUS can accurately predict production then it could be valuable for determining which heifers to develop for the milking herd (van der Fels-Klerx et al., 2001).

Producers should only pay for TUS if all relevant costs are lower than the value of information that is specific to their situation. For a producer who is crossbreeding Holsteins with a beef breed (Angus in our study) to sell feeder calves, net returns appear to be higher as they are kept longer. For such producers who plan to sell later, TUS is most practical in the presence of high BRD incidence rates. The value of TUS and BRD diagnoses information for a high BRD incidence rate is between $2.14/head and $7.10/head and depends on feed price and feeder price. While there still may be value to TUS and BRD diagnoses information at lower BRD incidence rates, it is significantly lower and likely not worth the cost. Changes in feed costs and changes in market price also impact the specific value associated with each scenario and should be considered in order to accurately predict the value of information.

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