THESIS

DETERMINANTS OF INVESTMENT: SEXED SEMEN IN DAIRY CATTLE

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY KATELYN MCCULLOCK ENTITLED DETERMINANTS OF INVESTMENT: SEXED SEMEN IN DAIRY CATTLE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

DETERMINANTS OF INVESTMENT: SEXED SEMEN IN DAIRY CATTLE

The process of sexing semen through flow cytometry has achieved results in several species, including humans. Potentially, the dairy industry has the ability to earn large gains from sexed semen because of the need for all female herds. This research examined key components in the areas of technology, management, and market environment that affect the adoption of sexed semen on a commercial dairy farm. A spreadsheet was built to simulate the interactions among these areas of interest and regression was used to map and simplify the results. Three scenarios were compared on a case farm using sexed semen. Results identify Dairy heifer calf price had the most impact on profitability of this technology. Conception rate and technology variables affecting conception rate also had significant impacts on return on investment.

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Chapter 1: Introduction

For many years dairy farmers have been using artificial insemination to impregnate their herds, and have essentially eliminated the need for bulls on the farm, although many dairies breed some of their cows naturally with bulls. Because of the lactation cycle, pregnancy in dairy cattle is very important to sustain milk production and raise replacement animals. Cows are monitored and frequently hormonally synchronized to ensure pregnancy and subsequently, milk flow is constant. Synchronization and constant monitoring removes the need for the bull's presence because the guess work of when cows come into heat has essentially been taken out of the equation. Artificial insemination allows delivery of semen to the cow at the correct time with little waste. Aside from the sperm, itself, and the genetics, bulls are of very little value, creating an ideal environment for sexed semen.

Sexed semen provides a twist on artificial insemination's relatively old technology. Sexed semen consists of sorting sperm from conventional artificial insemination straws by sex chromosomes, creating an ultimate product for a dairy farm. Dairy farmers not only can eliminate the need for bulls on the farm to impregnate cows; but by using sexed semen, they also cut down on the number of bull calves born as a by-product of breeding for replacement heifers.

Controlling the sex of offspring has two major advantages for dairies. The first is faster genetic progress by controlling not only the sire's genetics but also the dam's genetics.

Producers can choose which cows have heifer calves. With conventional semen, producers run the risk of their best producing cows having bull calves. The second advantage is that it leaves a larger part of the herd available to make gains in the non-replacement section of the herd. Originally, breeding a dairy herd would require breeding nearly the all the cows for the purpose of replacement animals; because only 50% would be give birth to female calves. Cows are normally only kept in the herd for less than three lactations, so they are replaced every five to six years. This leads to a replacement rate of greater than 30%, which leaves very little room for choosing the best animals out of the 50% heifers born as some calves die and others are infertile. Sexed semen ensures a female calf from the dam desired for about 90% of conceptions, so fewer animals need to be bred for the purpose of replacements. The animals that are not being bred for replacements then can be chosen to be bred for whatever market has an advantage. Advantages really depend on output prices. If heifer replacement prices are high, a dairy farm could breed the remainder of the herd for more heifers and sell them to other dairies. If the beef market offers a higher price, dairy farmers could breed dairy cows with beef semen and sell crossbred calves to feedlots.

1.1 Objectives

Of course with any technology, there are also disadvantages. This thesis is a feasibility study of using sexed semen on a commercial dairy herd. It strives to quantify the benefits and costs an operation may incur in the event of using sexed semen technology. Naturally, this technology is not for all herds, producers, and conditions. Here, ideas from past literature have come together in a model that seeks to identify the conditions where sexed semen is profitable for a commercial dairy. The central thought process focuses around the influences that can change the outcome of profitability: markets, producers, and scientists. The purpose is to provide producers and scientists with information about the market circumstances that make or break the feasibility of sexed semen and information about the areas of improvement they can focus on that will increase the circumstances where it will be viable.

1.2 Procedure

The method of analysis is a spreadsheet model that uses enterprise budgeting to quantify the changes in profit given different assumptions revolving around sexed semen. The model compares three scenarios of implementing sexed semen on a commercial operation against a control farm based on profit. Sensitivity analysis of the relative profit of sexed semen to unsexed semen to input variables was used to choose key inputs. Stochastic uniform distributions were applied to each key input variable, followed by a Monte Carlo simulation to generate data that maps the relative profit advantage of sexed semen to over 8,000 combinations of the key inputs for each scenario. Finally, the generated data is regressed over the key input variables to simplify a study of the relationships so that I could look for meaningful recommendations for managers and scientists about the conditions that determine the feasibility of using sexed semen for dairies. These results discuss market circumstances, and changes producers and scientists can make to accomplish successful implementation. Profit difference between the control farm and the three scenarios will be the judge of success.

The remainder of this thesis is organized into four parts. The first part is a journal article intended for submission after completion of my degree. The article is intended to be a full representation of the best that my analysis has to offer. Since journal articles cannot contain detailed information typically found in a thesis, the remaining sections are devoted to supporting information, including an extended literature review, an extended methodology, and an appendix including selected parts of the model. The journal article, chapter 2, is targeted towards an academic journal in Agricultural Economics. The article walks through the central thought process, the most pertinent literature, methodology, results, and conclusions. Methodology in Chapter 2 discusses the variables, path to choose those variables and the model's setup and inclusions. Simulation includes how the macro generated the data and describes the OLS regression. The result section in Chapter 2 discusses the areas where scientists and producers can make a difference on profitability and how to respond to market conditions. Lastly, this chapter highlights the conclusions, limitations and possible future research. The third chapter takes a deeper look at synthesizing the central thought process and past literature. The direct relationship between how technologies are formed and accelerate within an industry is linked to sexed semen and the historical process it has taken to reach its current status in the dairy industry. For sexed semen to reach its pinnacle within the dairy industry, it is important to see the areas in which improvements can be made, and the areas where it is futile to make changes. Lastly, Chapter 3 gives the contribution to the literature. Chapter 4, Extended Methodology, has greater detail on the model and spreadsheet used for this study. This section focuses on the structure of the model. The extended methodology section discusses greater detail in the model by describing the interactive relationships of the variables and assumptions and links them to the appendix where printouts of the model can be found.

Chapter 2: Journal

2.1 Introduction

As a NY Times article suggests (Neuman, 2009) sexed semen is defying nature in a way dairy farmers have been anticipating. Producers can now choose the sex of offspring and break nature's rule of an equal ratio of males to females. Sexed semen in dairy cattle has previously had limited adoption, since its availability in the 1970's. In its early development sexed semen suffered from several problems. Conception rates were very low, accuracy was marginal, and it was very expensive compared to conventional semen from a comparable bull. Since being introduced, conception rates are almost 90% that of conventional artificial insemination rates under ideal conditions, accuracy has increased to 90% and the price is selling as low as $18 premium per dose. Furthermore, its marketability has increased because it has become more efficient and has more applications within the dairy industry. Previously, breeding stock and coupling with other technologies such as in vitro fertilization has been its primary application.

By coupling technologies, a producer can synthesize efficiencies by spending the extra cash it costs to do in vitro fertilization and produce more eggs with a single dose of sexed semen (Hohenbeken, 1999). This would result in more fertilized eggs destined to be female than using in vitro or sexed semen alone. In vitro fertilization enables multiple eggs to be fertilized without the environmental and animal obstacles that exist in artificial insemination. Fertilization is a large part of the barrier with using sexed semen and artificial insemination. Conceivably, combining the two technologies would achieve more pregnancies and as a result more female offspring would be produced. As sexed semen technology has improved, both in efficiency and cost, it is now feasible for commercial farms to use sexed semen and artificial insemination for replacement purposes. However, for a commercial farm to implement sexed semen, factors other than the technology's efficiencies play a part in profitability.

Although implementation on commercial dairies is increasing, it is important to recognize that this was only possible by certain factors coming together. Technological breakthroughs have at least one thing in common; it takes the right people, combination of ideas, and place in time (economy) for a new advancement to take off (Hargadon, 2003). In the case of sexed semen, I've adapted this concept to identify three spheres of influence that would impact a sexed semen technology decision: the market environment, management, and technology. Sexed semen is more likely to be profitable, and therefore adopted, when conditions are ideal in all three spheres, and least profitable when conditions are unfavorable in all three spheres. Decision makers in the management sphere (dairy managers) can influence the conditions in their sphere to improve profitability, but are limited by conditions in the other two spheres. Likewise, scientists and technicians can influence the technology sphere. Scientists can change the manner in which semen is sorted to make more efficient conception rates, better accuracy and lower premiums. Even with improved technologies, profits on the dairy farm are still influenced by the other two spheres and scientists cannot change the conditions in the other two spheres.

The focal points of this study are these areas of influence. The framework of the model and study was developed based around these areas and their interactions. In the management sphere, producers have different strengths and weaknesses as managers and depending on how those strengths and weaknesses affect production could limit sexed semen's profitability. The variables in this sphere apply to variables that affect production. In the technology sphere, scientists and the industry have the ability to change the parameters of sexed semen in terms of how it affects a farm on a production level as well. Sexed semen has already seen improvements in accuracy, conception rates, and price. The variables in this sphere apply to variables that affect the tradeoffs between price and production gains. Finally, in the market sphere, changes to input and output prices are independent of individuals. However, certain price changes would greatly affect how managers and scientists behave to make sexed semen profitable to implement.

Visually, a Venn diagram can illustrate how the spheres work together to determine the feasibility of sexed semen technology. Three circles represent the three spheres of control; market environment, management, and technology. Figure 2.1 describes Region A, where the circles do not overlap, and indicate infeasibility. Region A is condition where changes in the any sphere will not create a positive investment. That is, there is nothing managers or technologists in the current market conditions can do to make sexed semen profitable. Figure 2.2 describing Region C, is the condition where all three circles overlap completely, and the condition in which variables in all spheres are at an optimal point for this technology. In this case, the market can

Figure 2.1: Region A: Infeasibility

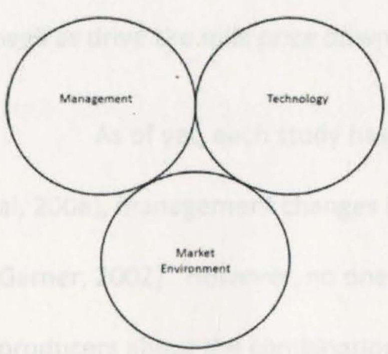


Figure2.2: Region C: Feasibility

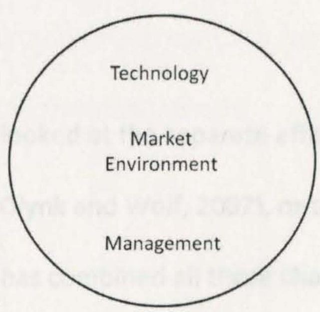
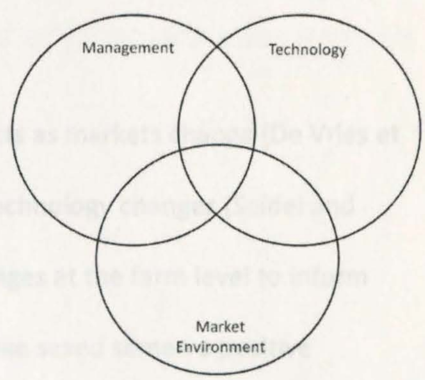


Figure 2.3: Region B: Conditional Feasibility



change, or managers or technologists can make changes with no chance of making sexed semen unprofitable. Figure 2.3 describes Region B, the areas where two circles can overlap, where there are conditions that can make sexed semen feasible. For example, in an overlap between management and market environment, technologists may be able to make changes that can move sexed semen into a profitable region.

Economists have analyzed and suggested applications for commercial use. Seidel and Garner (2002, 2003) suggested that with sexed semen a producer has the ability to use less of the herd for replacement numbers because the genetically superior animals can be chosen to produce female herd replacements with 90% certainty. Hohenboken (1999) suggested options for breeding stock, but also the use of combining sexed semen with a crossbreeding program to get the most dollars of the herd's non replacement group. Recently, several studies have looked at both the impact on the dairy industry and the investment of sexed semen. Olynk and Wolf (2007) studied the net present value (NPV) to assess the value of sexed semen as an investment. They varied management variables such as conception rates, inseminations, and scenarios, varying the number of animals, to describe situations where a farmer could invest in sexed semen. Another study (De Vries et al, 2008) looked at impacts of sexed semen on the fluctuation of industry prices. De Vries et al (2008) focuses on market changes that could occur such as flooding the market with dairy heifers, which would drive the dairy heifer price down, as well as drive the milk price down.

As of yet, each study has looked at the separate effects as markets change (De Vries et al, 2008), management changes (Olynk and Wolf, 2007), or technology changes (Seidel and Garner, 2002). However, no one has combined all these changes at the farm level to inform producers about the combinations of variables needed to make sexed semen a positive investment. The major contribution of this study is looking at all three areas of influence: management, technology, and market. The purpose is to identify the regions under each area of influence, where sexed semen technology will produce a better result than if the technology was not implemented at all. Once identified, the conditions in the regions of feasibility and infeasibility, C and A respectively, can be known by the producers and scientists as areas where they can't make a difference to the investment outcome. The marginal conditions, Region B, could then further notify scientists and producers where it is possible to make a difference to investment outcome.

Quantifying the situations where sexed semen would be feasible are generally thought to lie under two regimes, herd expansion through internal growth, and increasing the value of non-replacements with constant herd size. But as the NY Times article pointed out, excess cows may not be the answer for dairy farmers in a dwindling market (Neuman, 2009). This article focuses on the regime of constant herd size and increasing the value of non replacement animals. The net advantage of sexed semen depends on whether a producer would be making more profit than without the new technology. A control scenario quantifies baseline profit without sexed semen. Three additional scenarios were created to describe the ways sexed semen could be used while keeping herd size constant: 1) breeding only heifers with sexed semen for replacements, 2) breeding cows and heifers with sexed semen for replacement, coupled with conventional dairy semen, and 3) breeding cows and heifers with sexed semen for replacements, coupled with conventional beef semen.

actually occur from implementation. The spreadsheet was determined to start with certain basic characteristics of a dairy. The spreadsheet operates under the farm management practices of a 2500 head dairy. Reproduction practices include using Ovsynch exclusively, and heat detection is assumed to be 100%. Cows and heifers that fail to achieve pregnancy are rebred every 28 days until they are culled. It was assumed cows would be culled at the 7th service and heifers at the 4th service. A cull rate of 35% is assumed for the lactating herd. The cull rate attributes 25% for beef, 4% for dairy and 6% for mortality. The herd is broken down into three lactation groups which are grouped by age and with weighting of 35%, 28% and 37% for lactations one, two and three. Lactation group three also includes any older cows remaining in the herd. Heifer cull rates were set at 6%, and age of first breeding was set at 14 months. Once the characteristics of dairy farm were described, a structure was developed around quantifying the changes in a dairy caused by sexed semen.

Organized around partial and enterprise budgets, the spreadsheet simulates a year on the farm, capturing biological and protocol variables that affect outcomes. Those outcomes are then captured on a partial dairy budget, focusing on operating expenses and revenues to predict profit. Several sources were utilized to develop the partial budget, drawing from different universities, and talking with experts and producers.

The farm mimics a commercial dairy farm as described in the previous paragraphs and without sexed semen will act as a control study farm. Inputs and outputs related to sexed semen, as well as those related to day to day operations, are captured by the operating expenses and revenue to quantify annual profit. Variables related directly to sexed semen are added to simulate sexed semen implementation with a specific breeding strategy and simulates the relationship that strategy scenario has on the farm partial budget. Taking from the literature and discussions with scientists and producers, relationships were built into the model, creating a simulated use of technology.

Previous literature and experts suggested several impacts sexed semen will have on an individual dairy. The first is a decrease in the number of dystocia cases (Medalena and Junqueira, 2004). Particularly in heifers calving for the first time, larger calves frequently cause difficulty in calving, or dystocia. The economic impacts range from veterinary bills, loss in production and sometimes even the replacement of that animal. Bull calves are generally larger than heifer calves. Sexed semen can be attributed to a cost savings in dystocia, by having a lower incident of bull calves in animals having their first calf. Sexed semen also allows for faster genetic gain leading to an increase in milk production (Van Vleck and Everest, 1975; Seidel et al, 2003). After heifers born through sexed semen enter the herd and fill the lactation groups, the gains are fully realized by the dairy. Revenues from a surplus in replacement heifers may also be realized, as farmers can produce more heifers than they need. Increased expenses include feed costs as a result of increased milk production, and breeding costs related to increased number of inseminations and additional premiums for sexed semen. Adding these relationships to the model and variables specifically linked to sex semen, the model annualizes the effects of the technology and quantifies them on an annual profit basis. Focusing on the effect on annual profit, comparisons can be made between the control and a scenario. Importantly, the budget allows gains and losses for a specific budget item within the farm to be verified and the change measured.

The relationships created by those simulated changes required a large number of total variables. It was necessary to look at the total number of variables for the entire farm and select those that would most affect profit with the use of sexed semen. The total number of variables for the farm model was over seventy-five including those variables added for sexed semen. Some of these variables are assumptions based on the farms characteristics and biological capabilities of the animal, but it is noted that these could be changed in the model. The model was built to analyze the effect of sexed semen, and to do so, the seventy-five variables needed to be categorized and shrank to a manageable size based on the variables that mattered most for sexed semen.

Categorizing the variables was relatively simplistic. Variables were divided into four categories, each relating to the spheres of influence and a fourth "other" category. Variables were grouped into one of the three spheres if it pertained to be a variable of interest within that sphere. Other variables were set in a fourth category. The fourth category included farm practices, characteristics, and biological variables associated with cows. The idea of having a single case farm to compare the onset of sexed semen to a staid course made it easy to justify the fourth category as assumptions. After all, the variables that are of most importance are those grouped in a sphere. Although setting the fourth category as a control group of variables did help shrink the number of variables, there were still a large number in each sphere. Shrinking the focus to specific variables relied on the sensitivity of profit to each variable.

The variables grouped into a sphere category were then run through a sensitivity analysis to determine which would be considered key inputs. The key inputs determined to be those with the largest impact on profit per unit of change in the input. The sensitivity analysis was performed in Simetar™ using annual profit per cow as the determinant. Variables in each sphere of influence were subjected to a one percent change. Those that resulted in the highest change in profit as a result were identified as a key input variable for the respected sphere. In addition, because the interest was in the comparison of profits between the case study and a scenario, variables from preliminary results and literature that hypothesized to have an effect on the difference in profit were also added to the list of key inputs. The sensitivity analysis yielded the thirteen key inputs listed by sphere below:

Market Variables: milk price, price of corn, price of forage, price of bull calves, dairy heifer price and beef bull calf price.

Technology Variables: price premium of sexed semen, genetic gain, sexing accuracy, sexed semen conception rate factor for heifers and cows.

Management Variables: Number of inseminations in which sexed semen is used and conception rates.

The sensitivity analysis helped break down the number of independent variables to a manageable number and focus on the range of each key variable and set assumptions. The variables not chosen as key inputs were set at a typical industry level. Expert opinion (Seidel, 2009 and Wailes, 2009) verified the accuracy of these parameters and acceptableness of using them for the study in Colorado. It should be noted that three of these key input variables lead to deterministic relationships with other parameters in the model. Corn price was also hypothesized by Seidel (2009) to be correlated with soybean prices, a linear relationship between soybeans and corn was also enforced on soybean price. The second relationship is a linear correlation between beef steer prices and beef heifer prices, identified by observing historical data from the Livestock Marketing Information Center. The third relationship exists only in scenarios where sexed semen is used on cows. The number of cows bred is equalized to achieve the number of replacements needed. However, changes with the management conception rate variable and the number of sexed semen inseminations, affected the ability of cows to produce replacements. The percentage of cows given sexed semen was linked with those two variables in a step function. The function seeks the percent of cows needed to achieve all the replacements needed, by adjusting the percentage in accordance with the affect of the two other variables. Backwards calculations found the percentage of cows necessary based on three levels of conception rates and the three levels of inseminations. Furthermore, in certain cases it is not possible to have enough replacement heifers. It is then assumed that the producer suffers a loss at the same price as he would have been able to sell excess heifers. It was suggested that this was unrealistic, because a producer would not breed beef at all if not enough replacements. However, this is an anomaly in the model as well only occurring in less than 1.5% of the data in Scenario 3. Furthermore, because it was such a small percentage, it was not responsible for the majority of large losses in Scenario 3.

After identifying the key inputs, ranges were assigned to each variable. Because this model is exploring a response surface, the ranges were selected over what a typical range would be, not including extreme highs and lows. Table 2.1 provides a description of the key input variables as well as the applicable range chosen for that variable. Other variables not used as key inputs are located in the appendix as Figures A.1 and A.2.

The ranges came from multiple sources. Market sphere of influence variables, dairy bull calf price, corn price and forage price, had ranges chosen by expert opinion (Seidel, 2009 and Wailes 2009). Market variables of milk price, dairy heifer price, and beef bull calf price were identified by looking at historic data from the last five years from the Livestock Marketing Information Center. Variables in the technology sphere of influence: sexed semen premium, sex ratio, genetic gain from sexed semen, and the sexed semen conception rates for cows and heifers, were given by an expert (Seidel, 2009) on the scientifically possible range that could be achieved by the technology. The management variable number of inseminations with technology was chosen to be within the profitable ranges (i.e. inseminations that would certainly generate a loss, given any condition, were not used). The management variable conception rate was determined by expert opinion (Seidel, 2009). Once the levels of inputs and

Table 2.1: Variable Description and Applicable Ranges used in model.

Variable Name	Variable	Description	Range Low	Range High
MilkPrice	Milk Price	Price of Milk measured in dollars per hundredweight of milk	$10	$20
CornPrice	Corn Price	Price of Corn measured in dollars per bushel	$3	$6
ForagePrice	Forage Price	Price of forage measured in dollars per ton	$100	$130
BullCalfPrice	Dairy Bull Calf Price	Price of holstein bull calf measured as per animal	$40	$120
HeiferPrice	Dairy Heifer Calf Price	Price of replacement heifer measure as per animal	$160	$650
Beef Bull Calf Price	Beef Bull Calf Price	Price of calf measured as price of animal at 150lbs	$190	$290
CRMGT	Conception Rate Factor for Managmenet	Conception Rate measured as percent of benchmark conception rates	80%	120%
InswTech	Inseminations with Technology	Inseminations administered using Sexed Semen	1	3
SSPremium	Sexed Semen Premium	Dollars paid in addition conventional semen straw	$18	$22
SexRatio	Sex Ratio with SS	Percentage of Males to Females with sexed semen	84%	93%
SSGenetic Gain	Sexed Semen Genetic Gain	Percentage of genetic gain added by using sexed semen	0%	15%
SSCRCows	Sexed Semen Conception Rate for Cows	Conception Rate measured as a percent of conventional conception rate variable	75%	90%
SSCRHeifers	Sexed Semen Conception Rate for Heifers	Conception Rate measured as a percent of conventional conception rate variable	65%	90%

characteristics were determined, the relationships cementing them together solidified as well.

Knowing the interactive relationships between the spheres of influence, the variables within them, and the control variables allowed me to observe the changes in each scenario and compare it to the baseline, given the changes in key input variables. Essentially, the spreadsheet model takes the interactive relationships and synthesizes the results through the following financial equations:

$Profit_{T,i}$= Total $Revenue_{T,i}$-Operating $Expenses_{T,i}$ where i denotes the Scenario 1,2, or 3 and C is the case farm. x_1 to x_n relate to the 13 varying variables listed in the three spheres of influence above. T=1,2,3,4,5 years

Total $Revenue_{T,i}$=f(Milk Price, Heifer Price, Bull Price, Beef Bull Calf Price, Conception Rates, Sexed Semen Conception Rates, Sexing Accuracy, Sexed Semen Genetic Gain: all other revenues and biological factors held constant)

Operating $Expenses_{T,i}$= f(Corn Price, Forage Price, Price of Sexed Semen, and Number of Inseminations: all other costs and biological factors held constant)

The model incorporates the effect of each scenario separately and then compares that to what would have been achieved through the case farm. Importantly, the control is also affected by variables not specific to sexed semen, largely market, and some management variables. Allowing the control farm to vary with the scenario creates a hypothetical situation for an implementation scenario given the conditions. The regions are then better identified as a sole impact of using sexed semen on the control.

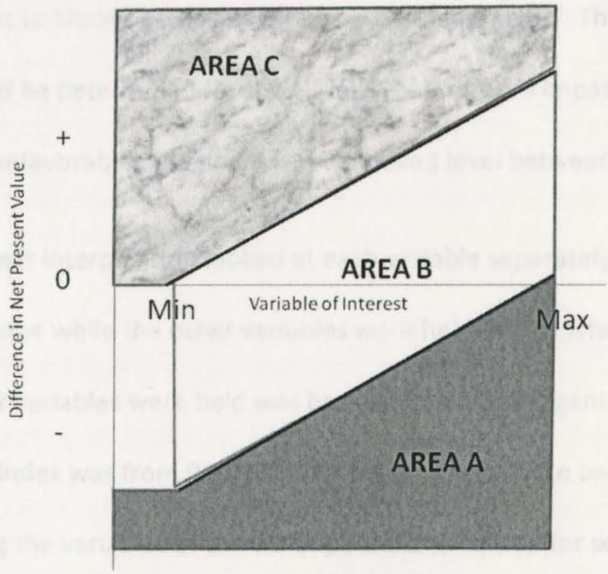
Even by using all the variables in these equations, the full effect of sexed semen was not realized in a single year's annual profit. Previous studies such as Olynk and Wolf (2007), and Outlaw et al (2007) have used net present value (NPV) as the key output variable for determining a production decision using sexed semen. Studies that have used this methodology are Leur et al (2008) and Hyde and Engel (2002). Both studies also used Monte Carlo simulation to determine a technologies investment worth. Sexed semen exhibits a production lag between implementation and maximum benefits. NPV is an appropriate measure of profitability because it captures the lag in benefits as well as the costs in earlier years. Higher milk production levels are expected with sexed semen in later years as heifers born from sexed semen enter the lactation groups. In this model sexed semen shows increasing returns from implementation until stabilizing at a higher constant return after five years in production. At five years, all the lactation groups are occupied by heifers coming from sexed semen inseminations and the production level will stabilize at new higher gain annually. To calculate net present value a stream of annual profit values generated the first five years of implementation for both the case farm and each scenario was used as inputs for a cash flow of five years at a nominal interest rate of 8%. Measuring profit for the first five years of implementing sexed semen will capture the production lag benefits and upfront costs. The key output variable will then be the difference in net present value between the case farm and the scenarios or sexed semen advantage (SSA). The SSA would then indicate if the farm was better or worse off using sexed semen, ceteris peribus.

Varying thirteen key inputs variables simultaneously, over differing ranges, would generate 10^{13} combinations if solved for ten values for each variable. This proved to be too many combinations to consider doing manually. A spreadsheet macro made it possible to draw a large sample subset from possible combinations through Monte Carlo simulations (Hyde and Engel, 2002 and Leuer et al, 2008). Hyde and Engel use Monte Carlo simulation to determine the breakeven net present value (NPV) in robotic milkers compared to a traditional parlor. Leuer et al (2008) used a stochastic capital budgeting model to analyze the effect of net metering policies and carbon credits on profitability of anaerobic digesters on Pennsylvania dairy farms. Leuer et al (2008) used Excel to develop their capital budget, and then used @Risk to specify distributions to vary the stochastic input variables. A constant seed was used across all simulations and 10000 iterations were performed. The Monte Carlo simulation determined if NPV was increased (decreased) by scenarios comparing policies and carbon credits. In this study, stochastic inputs are used without a constant seed to assign a uniform distribution over each of the thirteen key input variable's likely ranges, as reported in Table 2.1. The resulting profit was captured for each draw on a separate data sheet along with the thirteen key input levels. Net present value was calculated from the profit stream generated from variables. Each draw was held constant for five years. The macro calculates the difference in NPV between the case farm and each scenario, referred to as the sexed semen advantage (SSA).

The macro used for the Monte Carlo simulation reduced the number of combinations that had to be examined to about 8,000 for each scenario. A regression equation was used to sort out the determinants of investment; that is, to explore the response surface created by the Monte Carlo analysis. OLS (Ordinary Least Squares) regression determined the coefficients of each key input variable. The resulting regression was a linear equation for each scenario using SSA as the dependent variable. The regression equation is a tool to systematically determine the different situations, represented by the Venn diagrams shown earlier. The regression simplified the individual impacts of each variable to a single coefficient. The dependent variable, SSA, determines if the farm is feasible, infeasible, or conditionally feasible.

As described above, the regression makes it easier to determine the marginal impact of each variable, but also provides an opportunity to determine feasibility regions for the variables. Figure 2.4 is a graphical representation combining the regression equation and the Venn

Figure 2.4: Visual Graphic of Regions



diagrams to examine the impact of a single variable on SSA. One key input at a time is plotted on the horizontal axis using the regression equation against the SSA. The slope of the line shows the impact of that single variable on SSA, but the location of the line relative to the vertical axis tells a more important story. The line can take on three positions, everywhere above zero (Region C in the Venn diagram), everywhere below zero (Region A) and crossing zero (Region B). How much impact any one variable has will depend on the other twelve variables. If they are all favorable, the variable being graphed can change the magnitude of the SSA, but not the sign, where the line is everywhere above zero. Likewise, the line would be everywhere below zero, if the other twelve variable were unfavorable.

The location of the line is dependent on the other variables not being examined. Producers and scientists can only control the variables in their own spheres. Identifying the range for each region at which the other variables are held would provide the information individuals would need to see if they could change the investment outcome. It is possible to determine what the range of the other twelve has to be to determine the impact of each variable by using linear interpolation. First, identify the lowest index that could be determined for a variable of interest to always be positive (Region C or favorable). Then, identify the highest index that could be determined for the variable of interest's impact to always be negative (Region A or unfavorable). Region B is the indexed level between Region A and C.

Specifically, linear interpolation looked at each variable separately, as a variable of interest, changing its value while the other variables were held at a constant level. The constant level at which the other variables were held was based on an index organized by ordering the variables' ranges. The index was from 0 to 100, 100 being the absolute best condition for sexed semen, and 0 indicating the variables at the worst possible condition for sexed semen. An index of 50, for example, means that collectively, the variables are half as good as they could be. The individual impact of any one variable need not be 50 for the collective to be 50. This ranking is scenario dependent, as what is considered the best in one scenario is not the best in another. It also implies that in Figure 2.1 not all the variables are positive sloping but the same systematic approach was used to obtain their regions as well. The index created a score for the twelve variables held constant and impact of a single variable could be compared. Levels determined

Table 2.2: Index Levels by Variable and Scenario. This table gives examples of the index level and the numerical translation into a variable's range.

	Scenario 1		Scenario 2		Scenario 3	
Index	25	75	25	75	25	75
Milk Price	17.48	12.46	17.48	12.46	17.48	12.46
Corn Price	4.98	3.32	4.98	3.32	4.98	3.32
Forage Price	107.57	122.51	107.57	122.51	107.57	122.51
Dairy Bull Calf	99.07	60.01	99.07	60.01	99.07	60.01
Dairy Heifer	283.96	529.36	283.96	529.36	529.36	283.96
Beef Steers	264.95	215.32	264.95	215.32	215.32	264.95
CR MGT	0.90	1.10	0.90	1.10	0.90	1.10
Ins w.Tech	1.00	2.00	1.00	2.00	1.00	2.00
SS Price	21.00	18.99	21.00	18.99	21.00	18.99
Sex Ratio	0.86	0.91	0.86	0.91	0.86	0.91
SS Gen. Gain	1.04	1.11	1.04	1.11	1.04	1.11
SSCR Cows	0.79	0.86	0.79	0.86	0.79	0.86
SSCR Heifers	0.72	0.84	0.72	0.84	0.72	0.84

by quartiles created a base line to use linear interpolation and then calculated the breakeven index number for Regions A, and C. Table 2.2 shows examples of the levels for each variable by scenario.

Not all values of the index could be examined, so two levels were looked at for each variable the upper (most favorable) and lower (least favorable) quartiles of the Monte Carlo data. An index of 75 means that variables with a positive impact are set at their numerical upper quartile and variables with a negative impact were set at their numerical lower quartile.

The opposite was done for an index of 25. Variables with a positive impact were set at the numerical lower quartile and variables with a negative impact were set at the numerical upper quartile. For the collective index, all twelve variables were plugged into the regression equation at their indexed level. The variable of interest is then varied over minimum, maximum, upper and lower quartiles and the median. Two levels are then graphed using the dependent variable, SSA, on the y-axis and the value of the variable of interest is on the x axis. The location of the line matches the situations of the Venn diagram. Using indexes of 75 and 25, linear interpolation could be used to solve for the index levels at which the upper line crossed the horizontal axis at the minimum, and the lower line crossed at the maximum (for positive sloping lines, opposite for negative slopes). The line creates the upper and lower boundaries for Regions A and C. Region B is the space that lies between the lines. If the other twelve variables are in Region B, than an individual can conceivably manipulate the investment outcome. Regions A, B, and C were calculated for each of the thirteen variables and within each of the three scenarios, therefore thirty-nine regions were specified using this methodology.

2.4 Regression

The simulation generated data was cumbersome and did not easily reveal patterns of interest for my objective. The thirteen dimensions of the key input variables made the model difficult to work with in a strictly numerical basis. The data from the simulation was therefore regressed with the following OLS equations reported for each scenario.

SSA = NPV_i -NPV_C=f($x_1 \ldots x_{13}$: all other variables held constant) where i denotes the Scenario 1,2, or 3 and C is the case farm. x_1 to x_{13} relate to the 13 varying variables listed in the three spheres of influence above.

NPV =$\sum[\text{Profit}_{T,i}/(1+\delta)^T]$; T=1,2,3,4,5 years for i= 1,2,3,C; δ=discount rate=.08

2.4.1 Control Scenario

Under the control scenario a producer uses artificial insemination with conventional semen for all animals; replacement animals are taken from the naturally occurring sex ratio. The surplus animals are sold as non-replacements along with the bull calves. If there is a deficit, heifers are purchased to fill the need for milk cows entering the herd, while bull calves are sold. An important distinction between heifers and bull calves is the price differential. Heifer calves can be sold to other producers, for their deficit in heifers, while bull calves have very little value. Bull calves from commercial dairies usually are not stud quality, because their genetics are lacking.

2.4.2 Regressing Scenario 1

The first breeding scenario under sexed semen is to breed all heifers with sexed semen. Because sexed semen conception rates are lower than conventional semen, heifers are the ideal choice for sexed semen breeding, since they exhibit higher conception rates than cows (Seidel, 2009; DeJarnette et al, 2008; DeJarnette, 2005; Norman et al, 2009). Cows are given conventional semen for all inseminations.

Table 2.3 describes the coefficients found in the regression. The insignificant variables indicated for the Scenario 1 are as expected. Because the same prices were used in both the control and Scenario 1, feed prices were expected to be insignificant. The consumption of feed is not largely impacted by the use of sexed semen. However, forage consumption increases with increased milk production. The increase in milk production has a three year lag to the implementation of sexed semen. Furthermore, increase in milk production as a result of sexed semen varies with the variable genetic gain, and full potential is not realized until after the fourth year. In Scenario 1, beef calves are not a product of the operation; so the resulting insignificance is expected. Cows were not given sexed semen, so their conception rates were not affected by the use of sexed semen, as indicated by the SSCRCows variable being insignificant.

Table 2.3: OLS Regression Results for Scenario 1.
Coefficients measured in SSA dollars per cow.

Scenario 1: Only Heifers				
	Variable	Coefficient	T Statistic	P-Value
	Milk Price	-0.17	-3.71	0.00
	Corn Price	**-0.35**	-2.5	0.01
	Forage Price	**0.00**	0.06	0.95
	Dairy Bull Calf	-0.32	-53.82	0.00
	Dairy Heifer	0.32	339.95	0.00
	Beef Bull Calf	**0.00**	-0.72	0.47
	CR MGT	105.89	90.91	0.00
	Ins w.Tech	10.37	54.56	0.00
	SS Price	-2.18	-18.84	0.00
	Sex Ratio	279.56	54.36	0.00
	SS Gen. Gain	29.08	9.43	0.00
	SSCR Cows	**3.35**	1.08	0.28
	SSCR Heifers	212.93	113.53	0.00
	Constant	-582.80	-80.74	0.00
Bold Indicates Insignificance α=1%				
		R Squared:	0.9478	

A few coefficients appear to be extremely large compared to the other coefficients. The SSA is measured in dollars per cow. In addition, the ranges of CRMGT, SSSexRatio, SSGenetic Gain, SSCRCows, and SSCRHeifers have a smaller variance than the other variables. CRMGT has a range covering 0.40. SSSexRatio has a range covering 0 .06. While SSGeneticGain covers 0.15, SSCRCows has a spread of 0.15 and SSCRHeifers has a spread of 0.25. The above equation is using OLS regression on the thirteen independent variables. Interactive terms were investigated but did not prove to make a significant difference in the model.

A logistic regression or logit model was also run to simplify and normalize the impacts of the thirteen variables. Compared to the OLS model, the logit model answers a different question. OLS returns the dependent variable value as a predicted output for the values of the key input variables. The coefficients are in the units of the dependent variable (SSA/cow), making them easy to interpret. The logit model is predicting the likeliness of an event occurring. Logit models are based on Bernoulli's Trials where independent trials have only two outcomes and probabilities are known for an event. However, in logistic regression the probabilities are unknown and are estimated in a linear form with a stochastic error term. Independent variables' coefficients are estimated on how they relate to the probability of a binary choice of one or zero. The dependent variable is the binary choice. The odds of the event occurring would result in the dependent variable equaling one and the absence of the event occurring would equal zero. In this regression the logistic model is returning a value of one if SSA is positive and a zero if it is not positive (or negative). Essentially, we are estimating $P(y_i|x_i)$, where y is the event that SSA is positive, given the values of our thirteen key inputs. The logit mathematical form is as follows:

$Z_i=B_0+B_1x_1...+B_{13}x_{13}$ where x_1 through x_{13} are the thirteen key inputs as used in the OLS regression. Z, however, is a variable based on the coefficients and follows the non-linear (cumulative) logistic distribution of $F(z)=1/(1+e^{-Z})=P_i$ for values of Z being $(-\infty,\infty)$. Entering the value of Z into the distribution returns the binary choice of zero or one (referred to as the y value). P_i is the event of a one outcome and 1-Pi is the event of a zero. Furthermore, 1-Pi can be written as $1-P_i=1/(1+e^{z})$. The odds ratio is known as the probability of one event (Pi) happening over the probability that is does not $(1-P_i)$. Mathematically, the odds ratio combines the distribution of both probabilities.

Odds Ratio: $P_i/(1-P_i)=(1+e^{z})/(1+e^{-z})=e^{z}$ Therefore, the logit model can be rewritten as:
$\ln(P_i/(1-P_i))=B_0+B_1x_1...+B_{13}x_{13}$ OR
$\ln(\text{odds of } y=1 \text{ for given values of } x)=B_0+B_1x_1...+B_{13}x_{13}$

The dependent variable is the log of the odds and the coefficients are estimated in log of odds units. The anti-log of the coefficients returns the impact of a one unit change of an independent variable on the odds. The logit model does assume that the log of the odds is linearly related to all x_i. However, the probabilities are not linearly related (cumulative density function is sigmoid).

In the OLS regression, the ranges of the variables were quite large for some variables and small for others. A one unit change cannot always occur in the variables. For example, one unit change in SSGeneticGain is meaningless because the range is only over 0.15. The same problem exists in the logistic regression as well, but can be standardized. The odds ratio can be used to standardize some of these effects by comparing the variables at one standard deviation away from the mean, instead at a one unit change. The odds ratio will compare the impact of the variable on the odds of y =1. An odds ratio of one indicates the variable has no effect on the outcome; the probability of SSA being positive is equal to that of it being negative.

Adjusting the odds ratio standardizes the change in variables and is referred to as the adjusted odds ratio. The adjusted odds ratio compares all the variables at one standard deviation away from the mean by taking the anti-log of the coefficient multiplied by the variables standard deviation (e^(coefficient*Std Dev)). The importance of this can be seen through an example using numbers from Table 2.4. As discussed earlier a one unit change in the independent variable causes the odds to change by the coefficient and create the odds ratio. However, for some variables a one unit change is either not possible, or irrelevant. A one unit change in dairy heifer price would be $1, which is not a likely to be a relevant change, and by looking at the coefficients in Table 2.3, it does not change the odds by very much. Dairy heifer price has a coefficient of 0.17659, indicating a one dollar increase increases the odds of y=1 additively by .17659. The dairy heifer price odds ratio is 1.19 implicating that the odds of y=1 would increase by 1.19 times (if the odds were 3, and a one dollar increase occurred, ceteris peribus, then the new odds would by 3*1.19 =3.57). Compared to the odds ratios of the other variables, it is not as influential as some variables. Taking the standardization into account and looking at the adjusted odds ratio, we see that dairy heifer price has a much larger impact and by far it is the most influential variable in this scenario. This example demonstrates that by observing the adjusted odds ratio, the difference in the size of the ranges between the variables is compensated appropriately.

Table 2.4: Logistic Regression; Scenario 1. Variable coefficients measured in log of odds units.

SCENARIO 1				
Variable	Coefficient	Odds Ratio	Adjusted Odds Ratio	Standard Deviation
Milk Price	-0.15428	0.857	0.641	2.89
Corn Price	**-0.25296**	**0.7765**	**0.786**	**0.95**
Forage Price	**0.00429**	**0.9957**	**1.038**	**8.63**
Dairy Bull Calf	-0.17629	0.8384	0.018	22.84
Dairy Heifer	0.17659	1.1931	7.414E+10	141.74
Beef Bull Calf	**0.00113**	**1.0011**	**1.033**	**28.78**
CR MGT	38.755	6.78E+16	85.548	0.11
Ins w.Tech	-1.28195	0.2775	0.406	0.70
SS Price	-1.15832	0.314	0.262	1.16
Sex Ratio	89.34399	6.33E+38	10.206	0.03
SS Gen. Gain	18.77562	1.43E+08	2.259	0.04
SSCR Cows	**-0.42395**	**0.6545**	**0.982**	**0.04**
SSCR Heifers	88.91952	4.14E+38	566.775	0.07
Bold Indicates Insignificance α=1%				

Using the logit model, significance in the variables did not change. Observing the adjusted odds ratio (highlighted in table 2.4), it was concluded in Scenario 1 that Dairy Heifer (price), CRMGT, SSCRHeifers, and SSSexRatio had the greatest impact on SSA being positive.

These variables indicate that they are a major factor in determining if sexed semen is the right strategy using this scenario. Based on the odds, two of the variables that most impact sexed semen are technology variables. Scientists developing sexed semen should focus largely on the accuracy of sexing the semen, and the fertility of the sperm. Both of these factors can be affected by the speed and pressure at which the sperm is sorted. The CRMGT is a management variable, affected by the efficiency of the reproduction program on the farm. The odds here indicate the better the reproductive program the greater the chance that sexed semen can improve the farm's current situation by implementing sexed semen. Dairy heifer price appears to have the largest impact on SSA being positive. Table 2.4 indicates the coefficient, odds ratio, adjusted odds ratio and the standard deviation for Scenario 1.

2.4.2 Regressing Scenarios 2 and 3

In Scenario 2, heifers are bred with sexed semen as in Scenario 1; however, some of the cows are also bred with sexed semen. This scenario is designed so that a producer can breed his top producing cows with sexed semen to ensure a heifer calf from those specific cows with the best genetics. This allows for higher genetic gain, because of the ability to choose phenotypically and possibly genetically on the dam's side. The percent of cows given sexed semen is enough to cover the number of replacements needed to enter the herd. The remainder of the cows are given conventional semen for the subsequent inseminations. Scenario 3, breeds all heifers with sexed semen, and breeds the same number of cows as in Scenario 2. However, in this management decision the producer breeds the remainder of the cows to conventional beef semen for the consequential inseminations. This scenario allows the producer to switch markets when heifer prices are low and capture premiums that may exist in the beef calf market for crossbred animals.

Table 2.5 describes the results of the regressions for Scenarios 2 and 3. In beef and dairy scenarios the insignificant variables are as expected. The variables least affected by implementing sexed semen are the Forage Price and Corn Price, and the SSCRCows variable is now significant because of the use of sexed semen on cows. The Beef Bull Calf Price is also significant in Scenario 3 with the use of beef semen to produce crossbred offspring.

Table 2.5: OLS Regression Results for Scenarios 2 and 3.

Scenario 2: Cows Coupled with Conventional Dairy Semen				Scenario 3: Cows Coupled with Conventional Beef Semen			
Variable	Coefficient	T Statistic	P-Value	Variable	Coefficient	T Statistic	P-Value
Milk Price	-0.73	-13.62	0.00	Milk Price	-0.72	-9.09	0.00
Corn Price	**-0.26**	-1.61	0.107	Corn Price	**-0.22**	-0.92	0.36
Forage Price	**0.00**	0.17	0.862	Forage Price	**0.00**	-0.09	0.93
Dairy Bull Calf	-0.67	-100.08	0.00	Dairy Bull Calf	-1.84	-184	0.00
Dairy Heifer	0.68	625.19	0.00	Dairy Heifer	-0.54	-335.88	0.00
Beef Bull Calf	**0.00**	0.01	0.993	Beef Bull Calf	1.65	208.35	0.00
CR MGT	187.48	139.85	0.00	CR MGT	110.61	55.62	0.00
Ins w.Tech	9.53	43.56	0.00	Ins w.Tech	28.20	86.89	0.00
SS Price	-5.79	-43.52	0.00	SS Price	-5.69	-28.83	0.00
Sex Ratio	570.06	96.4	0.00	Sex Ratio	569.61	64.88	0.00
SS Gen. Gain	29.76	8.39	0.00	SS Gen. Gain	30.17	5.73	0.00
SSCR Cows	254.62	71.64	0.00	SSCR Cows	316.03	59.93	0.00
SSCR Heifers	214.64	99.45	0.00	SSCR Heifers	216.76	67.7	0.00
Constant	-1141.77	-137.46	0.00	Constant	-1103.78	-89.57	0.00
Bold Indicates Insignificance α=1%				Bold Indicates Insignificance α=1%			
	R Squared:	0.9824			R Squared:	0.96	

Table 2.6 reports the coefficients, odds ratio, adjusted odds ratio and standard deviation for Scenarios 2 and 3. The adjusted odds ratio calculated by the logistic regression model for Scenario 2 showed that Dairy Heifer (price), CRMGT, Sex Ratio, SSCR Heifers and SSCR Cows have the greatest capability of returning a positive SSA. This scenario also had some odd ratios very close to zero indicating that this variable's effect on the odds is very negative. Dairy Bull Calf price has an adjusted odds ratio of 0.001. In Scenario 3 Beef bull calves (price) had the largest impact on achieving a positive SSA. Compared to Scenarios 1 and 2, Scenario 3 did not have any other variables with very large impacts on SSA. However, it also has more variables with odds ratios close to zero, such as Dairy Heifer Price and Dairy Bull Calf price, which indicate greatly reducing odds of a positive SSA.

Table 2. 6: Logistic Regression; Scenarios 2 and 3.

SCENARIO 2					SCENARIO 3				
Variable	Coefficient	Odds Ratio	Adjusted Odds Ratio	Standard Deviation	Variable	Coefficient	Odds Ratio	Adjusted Odds Ratio	Standard Deviation
Milk Price	-0.36483	0.6943	0.349	2.89	Milk Price	-0.05913	0.943	0.843	2.89
Corn Price	**-0.40476**	**0.6671**	**0.680**	**0.95**	**Corn Price**	**-0.03978**	**0.961**	**0.963**	**0.95**
Forage Price	**0.02154**	**1.0218**	**1.204**	**8.63**	**Forage Price**	**0.00638**	**1.006**	**1.057**	**8.63**
Dairy Bull Calf	-0.32541	0.7222	0.001	22.84	Dairy Bull Calf	-0.19029	0.827	0.013	22.84
Dairy Heifer	0.32216	1.38E+00	6.772E+19	141.74	Dairy Heifer	-0.05317	0.948	0.001	141.74
Beef Bull Calf	**-0.01072**	**0.9893**	**0.735**	**28.78**	Beef Bull Calf	0.172	1.188	141.086	28.78
CR MGT	87.46906	9.71E+37	22958.605	0.11	CR MGT	14.00404	1.210E+06	4.991	0.11
Ins w.Tech	1.11337	3.0446	2.189	0.70	Ins w.Tech	2.56155	12.956	6.064	0.70
SS Price	-2.79382	0.0612	0.039	1.16	SS Price	-0.5383	0.584	0.536	1.16
Sex Ratio	173.15254	1.58E+75	90.194	0.03	Sex Ratio	45.99756	9.470E+19	3.307	0.03
SS Gen. Gain	14.02377	1.23E+06	1.838	0.04	SS Gen. Gain	4.88187	131.877	1.236	0.04
SSCR Cows	101.25289	9.41E+43	80.178	0.04	SSCR Cows	25.35737	1.030E+11	2.998	0.04
SSCR Heifers	85.17421	9.79E+36	433.946	0.07	SSCR Heifers	20.69208	9.960E+08	4.373	0.07
Bold Indicates Insignificance α=1%					Bold Indicates Insignificance α=1%				

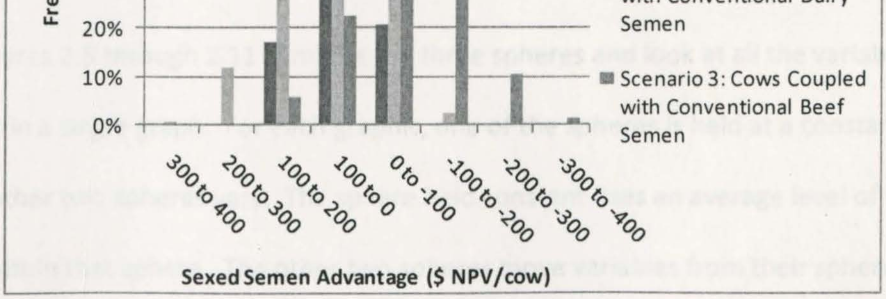
2.5 Discussion of Results

Results from both the regression and the raw data provide insight about how the thirteen key input variables affect SSA. First, a discussion on the distribution of the raw data, and how the SSA varies by each scenario. Second, a discussion of the regression results, and how the scenarios fit together with each other and the Venn diagram.

The simulated raw data simulated was hard to work with because the 8,000 runs of the simulation lead to about 160,000 pieces of information for each scenario. This information includes the thirteen variables, five years of profit, NPV, and SSA each with 8,000 points totaling 160,000 (8000*(13+5+1+1)). However, some useful information can be extracted from the data without regression. Each scenario has a unique distribution of SSA. A histogram shown in Figure 2.4 provides a visual of comparison for the scenarios' simulated SSA. Over 70% of simulations in Scenario 2 produced a positive SSA compared to over 25% in Scenario 3. Scenario

3 had the widest spread ranging all the way from less than $-300 to over $100 SSA/ per cow. The maximum for Scenario 3 was $259.43 SSA/ per cow. Scenario 1 had the smallest spread ranging from $ -100 to over $200 SSA/ per cow. Its maximum was $227.85 SSA/per cow. Scenario 2 had the highest maximum reaching $373.59 SSA/per cow. It is no surprise that Scenario 2 has the advantage, given the parameters of dairy heifer calf price. The breeding strategy in Scenario 2 produces the necessary replacement and fate determines the remainder of the offspring's sex Scenario 2 trims the breeding costs to only the necessary animals. By using conventional semen when heifer calf prices are high, Scenario 2 can also capitalize on the price advantage over beef calves. In Scenario 1, a larger part of the herd is given conventional semen. The void between the heifer calves produced from sexing and the replacement needs of the whole herd falls to the unsexed calves born by the cows. This results in fewer calf sales, indicated by a lower maximum then Scenario 2. In Scenario 3, dairy heifer calf price has a very different effect. When dairy heifer prices are high, the control farm has the advantage over Scenario 3, given the differential between beef and dairy heifer calf can be very large. However,

Figure 2.4: Histogram of SSA distribution by Scenario.



if dairy heifer calf prices are low, beef calf prices can have an advantage. The degree of the advantage, however, is smaller when heifer prices are high compared to beef. The majority of positive SSA results in Scenario 3 are a beef calf price advantage.

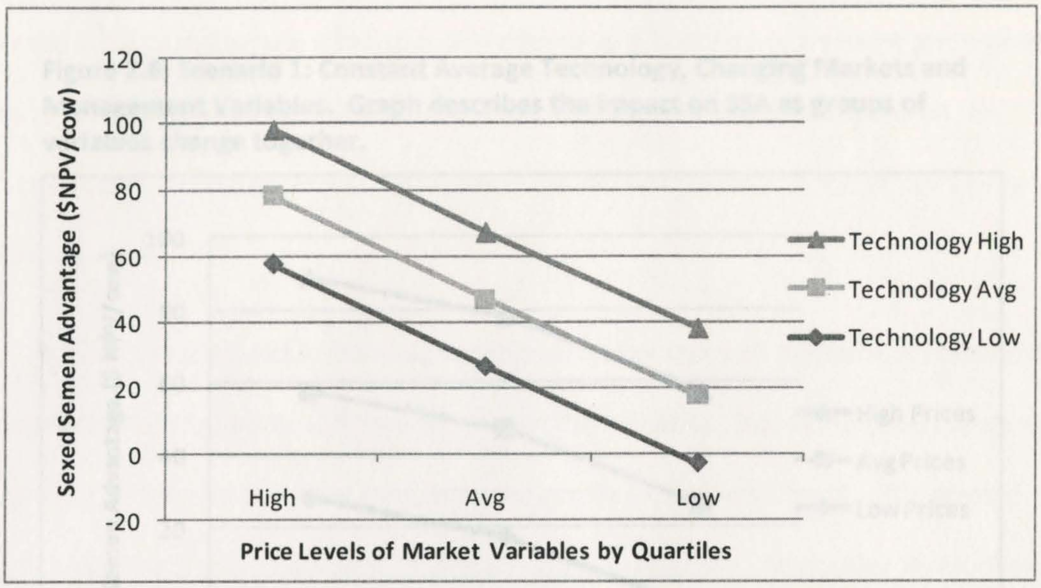
2.5.1 Scenario 1

More specifically, in Scenario 1, positive SSA is characterized by high heifer calf prices, high management conception rates, low dairy bull calf prices, high sexing accuracy, and high conception rate affect on heifers. Because all thirteen variables interact on the farm, some combinations do not exhibit all of these characteristics. It's important to remember that the positive nature of SSA is the difference in NPV between the scenario and the control farm. The case farm has the highest profit when inputs are low and output prices are high. Inputs, that are not largely affected by the introduction of sexed semen are irrelevant to SSA, were insignificant in the regression. Fewer dairy bull calves born as a result of using sexed semen have two effects. Dairy bull calf prices are better when they are low in Scenario 1 because fewer bull calves are produced. The price per bull calf represents an opportunity cost forgone in the control; the lower the price the lower the opportunity cost. Also, because there is a milk boost in production from bull calves, higher milk price in the control is good, while in Scenario 1, higher milk price represents another missed opportunity through less bull calves born. These directions are evident in the regression results in terms of insignificant variables, negative and positive signs.

Figures 2.5 through 2.11 combine the three spheres and look at all the variables collectively in a single graph. For each graphic, one of the spheres is held at a constant level, while the other two spheres vary. The sphere held constant uses an average level of the variables within that sphere. The other two spheres move variables from their sphere through levels of high, low and average. High, average, and low refer to the actual numerical quartiles of 75%, 50%, and 25%. For the purpose of these figures, the quartiles are not indexed from favorable to unfavorable as they are for the results relating back to the Venn Diagrams. The market sphere for the purpose of figures 2.5 to 2.11 includes sexed semen premium, because it relates to price. At each level the graphic uses the OLS regression results to plot three lines for the figures. The vertical axis represents the SSA, while the horizontal axis is the high, low and average for one of the spheres that is changing. The lines represent the last sphere that is changing from high, low and average. A single line, therefore, represents one sphere held an average level, and a second sphere held at the level that corresponds to the legend on the right. The points along a single line are then marking the level of the sphere on the horizontal axis, and its variables moving collectively from high to average to low levels.

The regression from Scenario 1 also led to some interesting results. Figure 2.5 shows changing market and technology, while holding management constant at an average level. Price is varied along the horizontal axis and the three levels of technology are shown as different lines. Two points are evident. The first is that the slopes are parallel and evenly spaced; indicating that changing technology from one level to the next varies linearly. Secondly, when management is fixed, technology can shift SSA into the positive range when market prices are low. Otherwise, technology can increase the SSA, but it will always be profitable.

Figure 2.5: Scenario 1: Constant Average Management, Changing Markets and Technology Variables. Graph shows impact of varying groups of variables on SSA.

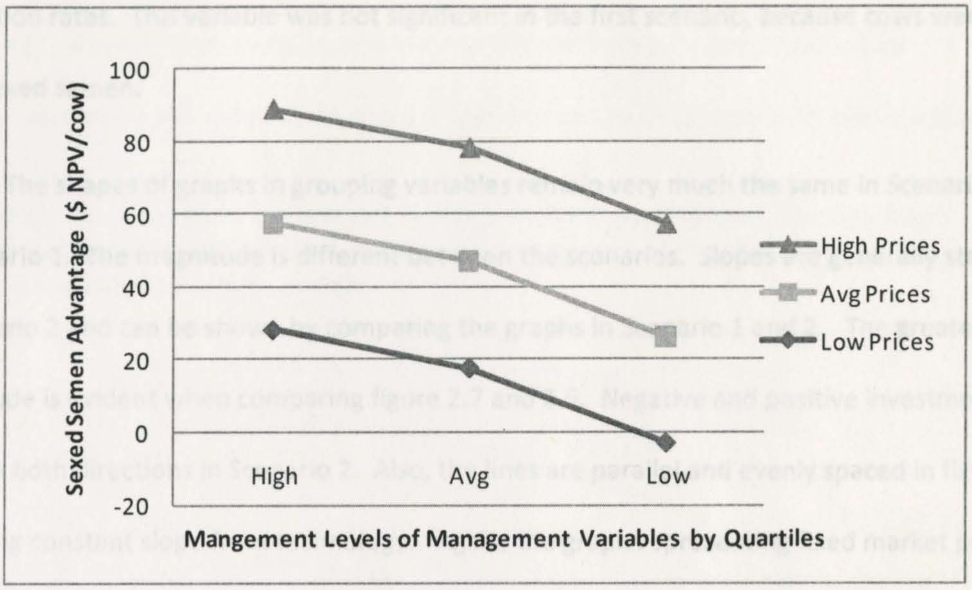


Although not shown, changing management and technology variables, and fixed market prices, yields a similar graph to Figure 2.5. The slopes are parallel; indicating the relationship between management and technology is linear. Although the lines are parallel, they are not evenly spaced; indicating linear interpolation may yield a possibly biased result. Different from the graph above, the three lines are above zero even at the lowest levels, indicating a positive investment (SSA).

The other example concerning Scenario 1 is shown in Figure 2.6, where technology is fixed and market and management variables are varied. Management in this graph has a changing slope, becoming steeper as management becomes worse. The changing slope is most likely an indicator of the Insemination With Technology variable being an integer. Moving from average to low shifts the value down by one. Moving in the opposite direction average to high, there is not a shift in that variable, because the upper quartile was at the same level. The market prices in this graph are parallel, indicating a constant slope as the different prices take effect. When market prices are low, management make a difference in the positivity of SSA.

Otherwise, increasing management increases SSA by about $20 per 25 % degree of improvement.

Figure 2.6: Scenario 1: Constant Average Technology, Changing Markets and Management Variables. Graph describes the impact on SSA as groups of variables change together.



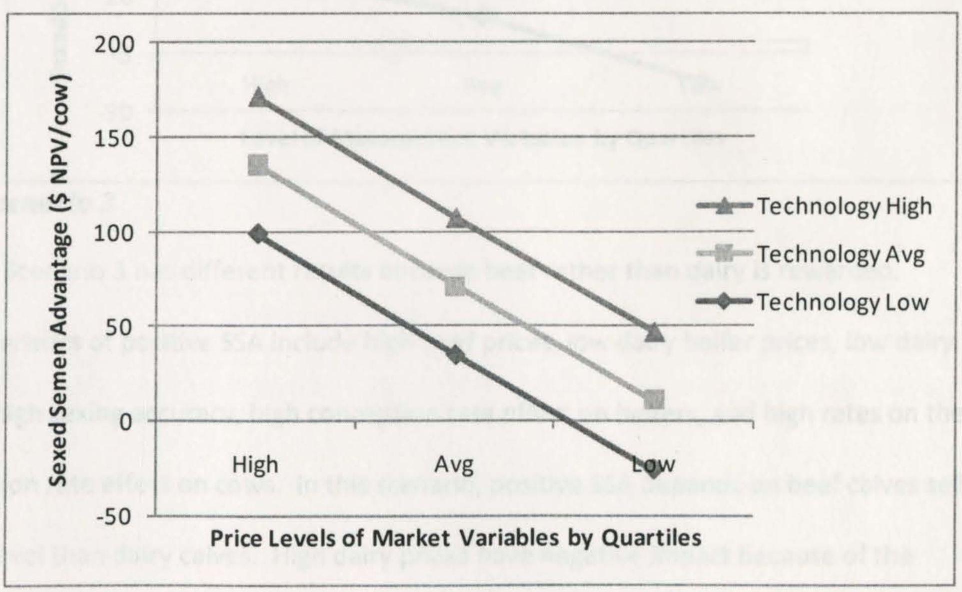
Recapping Scenario 1, prices seem to be the most influential on positive values. In both cases, when prices are low, and one of the other groups of variables is low, there is a negative return. However, low prices can be overcome in this scenario with better management, and better technology. Further discussion on the specific variables within each category make the most difference is presented in Regions Results Section.

2.5.2 Scenario 2

Scenario 2 yields positive SSA to the same collection of variables as in Scenario 1: high heifer calf prices, high management conception rates, low dairy bull calf prices, high sexing accuracy, and high conception rate affect on heifers. Scenario 2 also includes high conception rate affect on cows. Scenario 2 is a very similar to Scenario 1. The same logic applies as in Scenario 1 for each variable, but the opportunity costs and gains are bigger in Scenario 2 because more of the herd is dedicated to those outcomes. Variable signs remained unchanged in the regression between 1 and 2. However, one variable became significant in the Scenario 2 regression that was not significant in the Scenario 1 regression. The variable SSCR Cows is a significant variable in Scenario 2 because unlike Scenario 1, some cows are being given sexed semen as part of the breeding strategy. SSCR Cows is the effect sexed semen has on the conception rates. This variable was not significant in the first scenario, because cows were not given sexed semen.

The shapes of graphs in grouping variables remain very much the same in Scenario 2 as to Scenario 1. The magnitude is different between the scenarios. Slopes are generally steeper in Scenario 2 and can be shown by comparing the graphs in Scenario 1 and 2. The greater magnitude is evident when comparing figure 2.7 and 2.5. Negative and positive investments are larger in both directions in Scenario 2. Also, the lines are parallel and evenly spaced in figure 2.7 indicating constant slope from technology. Again, the graph representing fixed market prices,

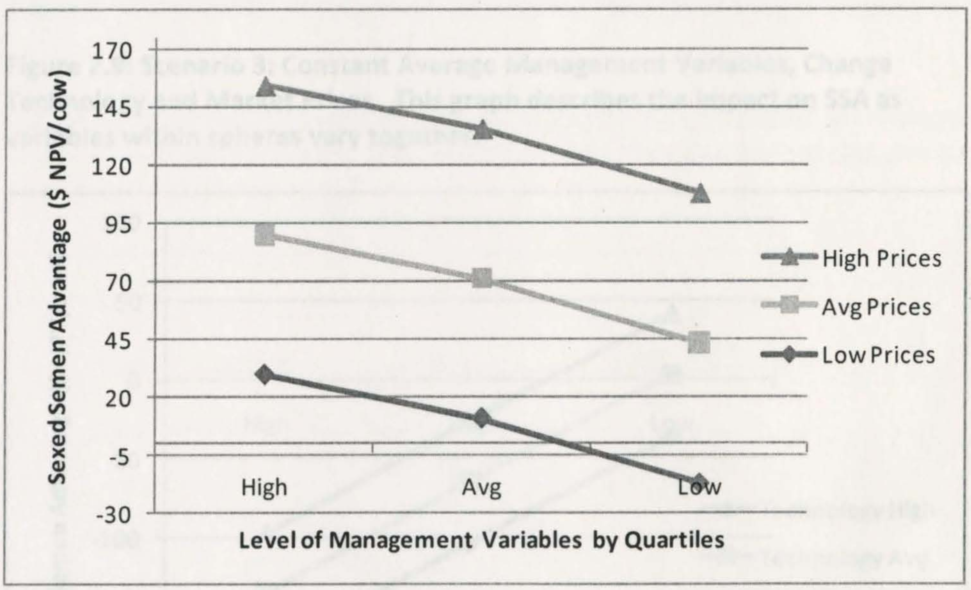
Figure 2.7: Scenario 2: Constant Average Management, Changing Management and Technology. This graph describes the impact of changing groups of variables from different spheres on SSA.



although not shown here, still does not exhibit a negative investment range but steepness of slope has increased from Scenario 1 to Scenario 2.

The final graph, Figure 2.8, examines fixed technology, changing management and market prices. Notice in the figure, the slope is less steep compared to figure 2.6, indicating less of an effect between high, average, and low management, than in Scenario 1. Low management levels are inhibiting to sexed semen but can be overcome with average prices.

Figure 2.8: Scenario 2: Constant Average Technology, Changing Management and Market Variables. This graph shows the impact of the changes in groups of variables by sphere on SSA.

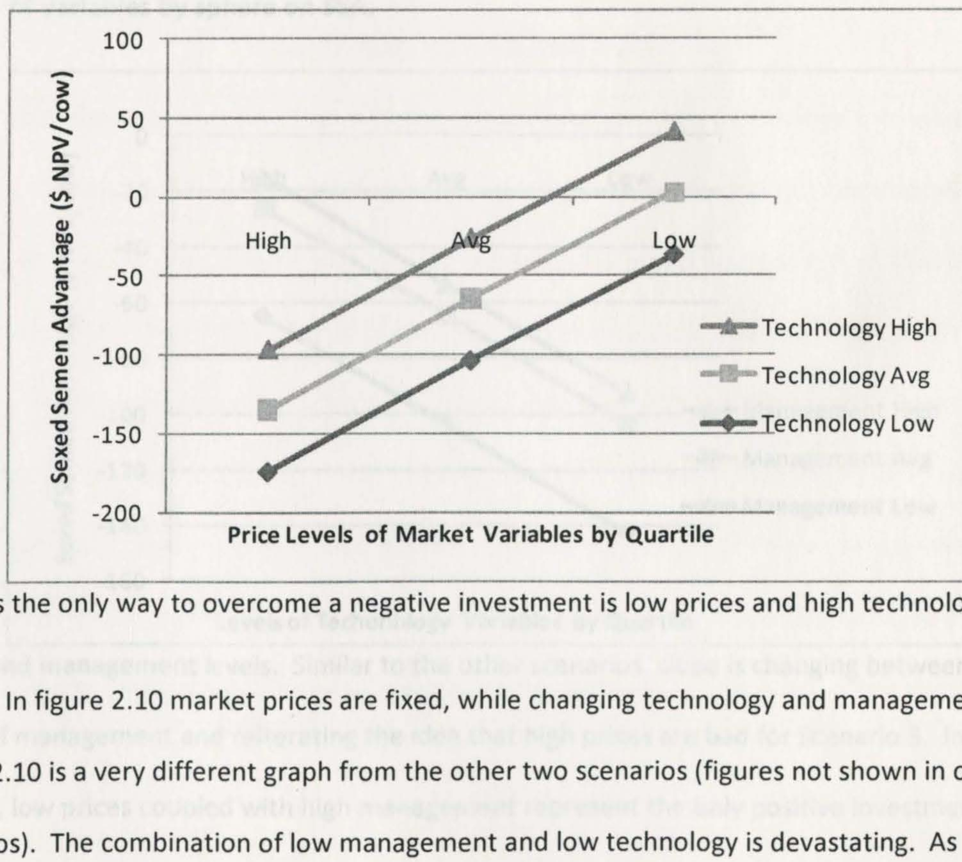


2.5.3 Scenario 3

Scenario 3 has different results because beef rather than dairy is rewarded. Characteristics of positive SSA include high beef prices, low dairy heifer prices, low dairy bull prices, high sexing accuracy, high conception rate effect on heifers, and high rates on the conception rate effect on cows. In this scenario, positive SSA depends on beef calves selling at a higher level than dairy calves. High dairy prices have negative impact because of the opportunity cost. The greater the difference between the two markets the more opportunity there is in one market versus the other. If the beef market is higher than the dairy market, Scenario 3 is going to produce positive SSA.

Figure 2.9 displays the result of fixed management, and changing market prices and technology under Scenario 3. In the Figure 2.9 high prices have the largest negative impact, while the lines exhibit constant slope. Notice the lines have changed direction from the previous two scenarios. Many of the variables have an opposite effect on SSA in Scenario 3 than in Scenarios 1 and 2, and are evident by the sign change between the OLS regression results. The lines are parallel and evenly spaced suggesting that technology gains are constant. It

Figure 2.9: Scenario 3: Constant Average Management Variables, Change Technology and Market Prices. This graph describes the impact on SSA as variables within spheres vary together.

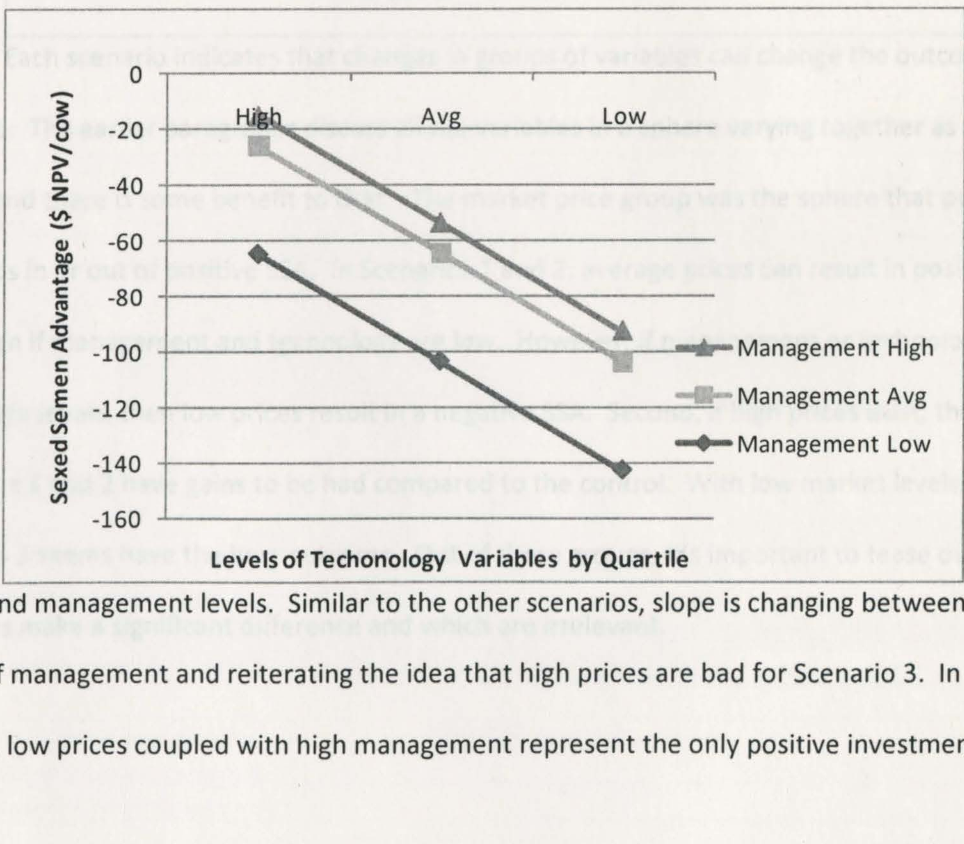


appears the only way to overcome a negative investment is low prices and high technology.

In figure 2.10 market prices are fixed, while changing technology and management. Figure 2.10 is a very different graph from the other two scenarios (figures not shown in other scenarios). The combination of low management and low technology is devastating. As was stated earlier, it is not always possible to produce enough heifers for replacement purposes. Low management in this case indicates that replacements must be bought at the market price of replacement heifers. Once moved to the level of average and high management, replacements are no longer need to be purchased, and a large jump in profit shifts the line closer to positive values. These lines are also not evenly spaced indicating a possible bias in linear interpolation. In figure 2.10 not one of the lines are above zero, implying that with prices at that level, even the highest level of management and technology is not enough to achieve a positive investment with this scenario.

Figure 2.11 represents the situation with median fixed technology and changing market

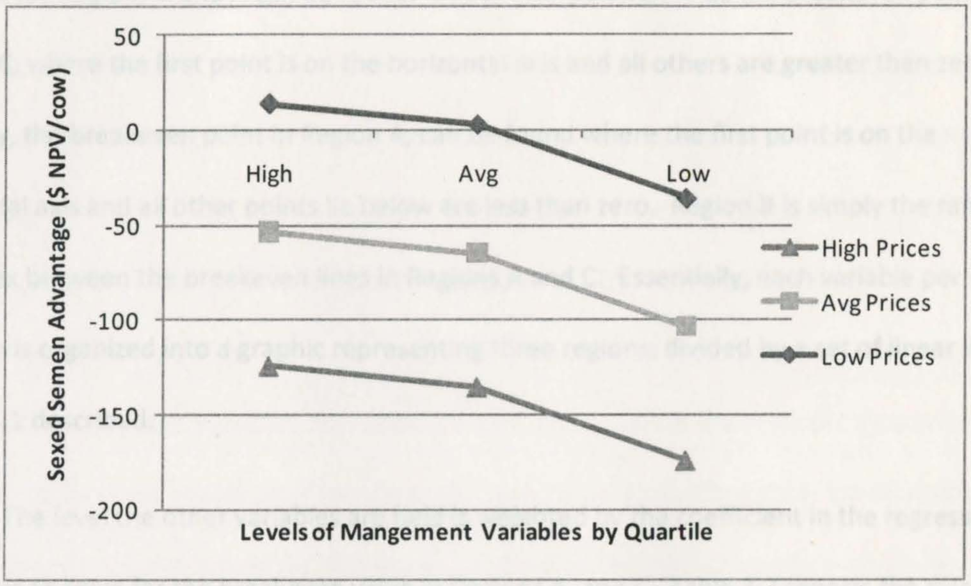
Figure 2.10: Scenario 3: Constant Average Market Prices, Changing Technology and Management Variables. This graph describes the impact of varying groups of variables by sphere on SSA.



prices and management levels. Similar to the other scenarios, slope is changing between the levels of management and reiterating the idea that high prices are bad for Scenario 3. In this graphic, low prices coupled with high management represent the only positive investment.

With low prices, beef calf prices and dairy calf prices are closer in value, shrinking the disparity between them.

Figure 2.11: Scenario 3: Constant Average Technology, Change Market Prices and Management Variables. This graph shows the changes in SSA as groups of variables from two spheres vary together.



Each scenario indicates that changes in groups of variables can change the outcome of a scenario. The earlier paragraphs discuss all the variables in a sphere varying together as a group, and there is some benefit to that. The market price group was the sphere that pulled scenarios in or out of positive SSA. In Scenarios 1 and 2, average prices can result in positive SSA, even if management and technology are low. However, if management or technology is set at average levels, then low prices result in a negative SSA. Second, if high prices exist, then Scenarios 1 and 2 have gains to be had compared to the control. With low market levels, Scenario 3 seems have the best outcome. Out of these groups, it's important to tease out which variables make a significant difference and which are irrelevant.

2.5.4 Region Results

Returning to the original Venn diagram, each variable has a special region for each scenario. Recall in the methodology section, linear interpolation and an index identified these regions. In almost all cases the index level for the other twelve variables to create a breakeven scenario for Regions C and A can be found. Linear interpolation finds the breakeven point in Region C, where the first point is on the horizontal axis and all others are greater than zero. Similarly, the breakeven point in Region A, can be found where the first point is on the horizontal axis and all other points lie below are less than zero. Region B is simply the range in the index between the breakeven lines in Regions A and C. Essentially, each variable per scenario is organized into a graphic representing three regions, divided by a set of linear lines, as Figure 2.1 described.

The level the other variables are held is weighted by the coefficient in the regression equations to solve for the breakeven value in Regions A, and C. Table 2.7 reports the calculated

Table 2.7: Index Levels for Regions A, B, and C for Scenarios 1, 2 and 3.

	Scenario 1			*Scenario 2*			*Scenario 3*		
Variables	Region A	Region B	Region C	Region A	Region B	Region C	Region A	Region B	Region C
Milk Price	37.4%	0.53%	37.9%	38.9%	1.12%	40.0%	59.0%	0.84%	59.9%
SSCR Heifers	25.9%	18.58%	44.5%	34.3%	8.89%	43.2%	56.6%	6.7%	63.4%
Forage Price	37.4%	0.01%	37.4%	39.6%	0.01%	39.6%	59.4%	0.01%	59.4%
Dairy Bull Calf	32.4%	8.04%	40.5%	34.3%	8.95%	43.2%	51.1%	20.55%	71.6%
SS Price	35.7%	2.64%	38.4%	37.4%	3.66%	41.1%	58.3%	2.72%	61.0%
SS Gen. Gain	36.6%	1.31%	37.9%	39.2%	0.69%	39.9%	59.1%	0.5%	59.7%
Ins w.Tech	31.7%	6.54%	38.2%	37.9%	2.35%	40.3%	54.8%	7.02%	61.8%
SSCR Cows	37.3%	0.15%	37.4%	35.8%	6.18%	42.0%	57.0%	5.83%	62.8%
Dairy Heifer	N/A	$ 411.73	69.2%	N/A	$ 425.04	80.7%	41.1%	44.64%	85.7%
CR MGT	28.6%	14.29%	42.8%	31.9%	12.88%	44.8%	57.2%	5.42%	62.6%
Sex Ratio	32.4%	8.04%	40.4%	34.5%	8.48%	43.0%	56.8%	6.34%	63.1%
Corn Price	37.2%	0.34%	37.5%	39.5%	0.13%	39.7%	59.3%	0.08%	59.4%
Beef Bull Calf	37.3%	0.10%	37.4%	39.6%	0.00%	39.6%	41.0%	15.36%	56.3%

Below the percentage in column is Region A | [shaded] Indicates negative slope

Above the percentage in column is Region C

Region B is the Difference between A and C index level as a percentage found through linear interpolation. The left most column is the variables of interest that would be located on the horizontal axis in figure 2.1, and index percentage is the collective score the other variables would be set at for the breakeven value. Region B is reported as the difference between Regions A and C. For example, Milk Price in Scenario 1 has 37.4% under Region A. This means that when Milk Price is at its minimum value the other variables have to be at an index level of 37.4% to equate the regression equation to zero. Because milk price has a negative sign, an increase in milk price to the lower quartile indicates a decrease in SSA, ceteris peribus. Therefore, this line is the breakeven point for Region A, because at an index level of 37.4% and below, SSA will always be negative. The same concept applies for Region C. An index level of 37.9% indicates that when milk price is at its maximum, all the other variables have indexed a 37.9% to equate the regression equation to zero SSA. A decrease in milk price increases SSA, ceteris peribus. Therefore, for all indexed levels above 37.9% SSA is positive. Region B is defined as the index levels between Regions A and C. For milk price that only leaves a range of 0.53%. For every index level between that range, milk price will be the deciding factor in the sign of SSA.

In some cases, variables do not have all three regions, and then the breakeven level for the variable of interest is reported. The only variable for which this occurred is dairy heifer price. In this case, when all other variables are held at an index of 25% there still remains values in both the negative and positive SSA. Region A does not exist for dairy heifer price and every index level below Region C is therefore in Region B. For this occurrence, Region B then reports the breakeven value within the range of dairy heifer price at an index level of 25%.

Recall the index is ranked from favorable (100) to unfavorable (0). In Scenario 1 all the percentages for Region A lie below 40% indicating that conditions would be poor in general to create a situation where sexed semen would be less profitable then the control. Interestingly, for Region C the majority of percentages are below 50%, indicating sexed semen would make a producer better off in below average conditions. Dairy Heifer Price is the only variable in this section to have an upper region of greater than 50%. Dairy Heifer Price does not have a Region A, meaning that even at the 25% level, there are still regions of profitability. The breakeven price of $411.73 (at an index level of 25) is slightly above the median dairy heifer price of $405. Variables with a larger difference in Region B indicate steeper slopes and a greater ability to change the outcome. The variables with the largest capabilities of manipulating the outcomes are the effect of sexed semen on conception rates in heifers, managements effect on conception rates, and dairy heifer price.

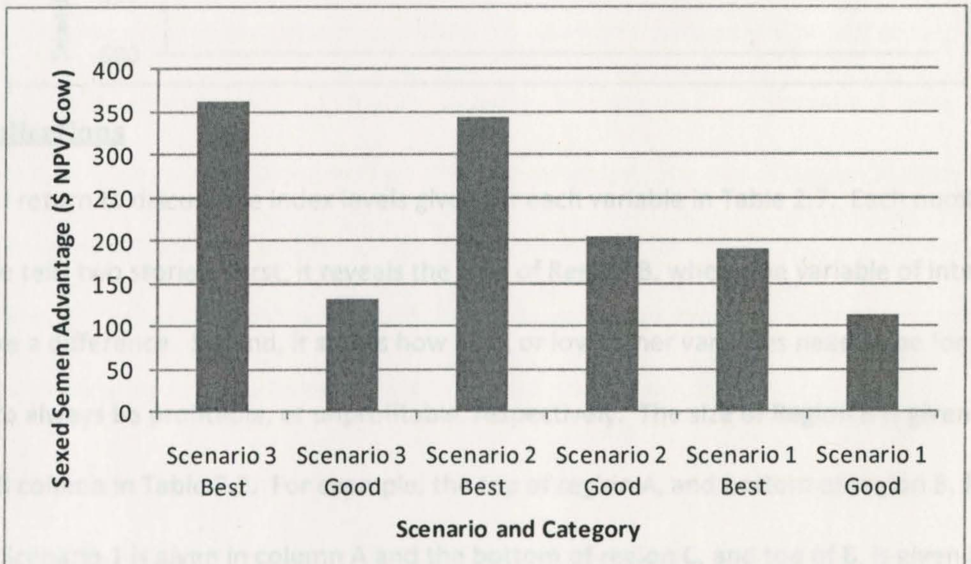
In Scenario 2 all percentages indicating the floor are also below 40%, however in this scenario the ceiling for most variables is greater than 40%. Prices for the other variables need to be closer to the median than in Scenario 1 for most variables. Dairy Heifer Price does not have a Region A in this scenario either and a breakeven price is slightly higher. Variables indicating the greatest impacts on the comparative investment are the effect of management on conception rates, the effect of sexed semen on heifers, dairy bull calf price and the sex ratio. Smaller Region B values also indicate less area existing in Region B, and less opportunity to change profitability given the conditions.

In Scenario 3 both Region A and C percentages are much higher. This indicates most variables need to be in a good position for sexed semen for this scenario to be larger than the control. This scenario also has the ability to make the largest gains as indicated by the regression. Scenario 3 is the only scenario where heifer price is advantageous to be low, thus indicating the negative slope. Producing the heifers only for your own replacements, and beef calves for the other animals, is only advantageous if heifer price is below beef calf prices or the farm cannot produce enough replacements and must buy animals. The variables in this scenario with the largest impact are beef steer price, dairy bull calf price, and dairy heifer calf price. Dairy heifer calf price does have a Region C. However, it's also moving in the opposite direction as the other scenarios.

Looking at the total index scores in each region by scenario, there are several conclusions to be drawn. Scenario 3 had the smallest total Region B for all the variables, indicating the least fluctuation, both controllable and uncontrollable. The fluctuation in the B Region for the other two scenarios is largely attributed to dairy heifer price not having a Region C. Unfortunately most of the variance comes from the market sphere in all three scenarios. Scenario 3 had the least amount of Region C and the highest in Region A in index scores. Scenario 1 has the largest in Region C scores and the least in Region A, making it a safer bet compared to Scenario 2.

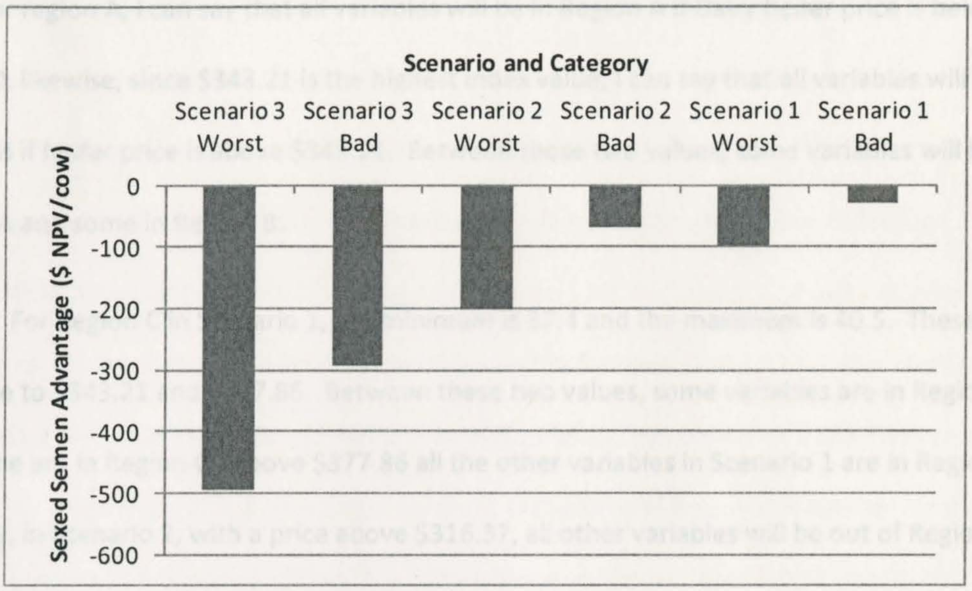
The last question perhaps to answer is which scenario makes the largest gains and the largest losses. Figure 2.12 applies the same idea of having better conditions and worse conditions for each scenario to represents the optimal conditions for each scenario. This graphic follows along the same lines as the indexed scores and using the regression equations. In Figure 2.12 the columns indicating "Best" for the given scenario implies that variables with the most impact are held constant at an index of 100. The other variables are varied through their median. The columns in Figure 2.12 labeled "Good" for each scenario, relies on high impact variables being set at an indexed value of 75, and all other variables are varied through their median. Those values are then used in the OLS regression equation and weighted by the coefficients. Scenario 3 has the capabilities of producing the highest advantage, though in the raw data with actual data it did not. This brings up the two important points. The regression is a line fitted to the data based on least squares and that its accuracy is based off of the simulated data. The second is that the simulation is a sampling of values that could exist. In the beginning of this paper, it was stated that 10 levels of each variable would lead to 10^{13} combinations, 8,000 is only a very small portion of even that number. The simulation did not necessarily pick the values in the combination that has been done for figure 2.12. Scenario 2 had the second highest, and third is Scenario 1.

Figure 2.12: Scenario Comparisons of Best and Good. Graph uses regression with index levels of 100 and 75 and plots SSA of the vertical axis.



Similarly, Figure 2.13 represents the worst conditions; the index score of 0 for the variables with the greatest impact and the median level for the other variables in the worst condition. In the "Bad" condition variables with the highest impact were held at an index score of 25, while other variables were held at their median levels. Scenario 3 was capable of producing the largest losses, having the most negative results for both the worst and bad conditions. Scenarios 1 and 2 had the abilities to have the least, worst conditions when using sexed semen.

Figure 2.13: Scenario Comparison of Bad and Worst Conditions. Graph uses index levels of 25 and 0 in the regression equation to plot SSA as a result.



2.6 Implications

I return to discuss the index levels given for each variable in Table 2.7. Each number in the table tells two stories. First, it reveals the area of Region B, where the variable of interest can make a difference. Second, it shows how high, or low, other variables need to be for sexed semen to always be profitable, or unprofitable, respectively. The size of Region B is given in the Region B column in Table 2.7. For example, the top of region A, and bottom of region B, for Milk Price in Scenario 1 is given in column A and the bottom of region C, and top of B, is given in the Region C column. The width of this range is 0.53 %.

The implications of the second piece of information may be more difficult to follow. The high and low index in each column, for Region A, B and C, for each scenario defines boundaries that can be used to make sweeping judgments about any particular variable. Furthermore, each index level linked to its corresponding value from each variable's range (Table 2.2) to make it more intuitive. For example, the most influential variable in all three scenarios is dairy heifer price. The range in Region A, Scenario 1, is from 25.9 and to 37.4. This high and low translate into dairy heifer prices of $286.80 and $343.21, respectively. Since $286.8 is the lowest index value for region A, I can say that all variables will be in Region A if Dairy heifer price is below $286.80; likewise, since $343.21 is the highest index value, I can say that all variables will be in Region B if heifer price is above $343.21. Between these two values, some variables will be in Region A and some in Region B.

For Region C in Scenario 1, the minimum is 37.4 and the maximum is 40.5. These translate to $343.21 and $377.86. Between these two values, some variables are in Region B and some are in Region C. Above $377.86 all the other variables in Scenario 1 are in Region C. Similarly, in Scenario 2, with a price above $316.37, all other variables will be out of Region A. A price of $379.50 and above will put all other variables into Region C. In Scenario 3, dairy heifer price moves in the opposite direction. For all other variables to be out of Region A, dairy heifer price must be above $449.27 and for all the other variables to be in Region C, a price has to be below $298.97. Based on these price levels, and the knowledge that it has a large impact on the scenarios, implications can be taken away from these price break downs.

The index levels can act as a guide to which scenario is the best choice based on dairy heifer price. Rounding to the nearest $25 increment, if the price is below $300, Scenario 3 is most likely to have positive outcomes. When prices are $300 to $350, Scenario 3 will be more likely to have positive outcomes. When prices are $350 to $375, Scenario 1 is the most likely to have positive outcomes. Finally, when prices are $375 and above Scenario 1 and 2 are more likely to have positive outcomes, and Scenario 3 will have some positive values.

2.7 Conclusion

Sexed Semen like any technology has its advantages and disadvantages. The model and results I have shown reveal the instances of profitability using sexed semen given the set of assumptions I have assigned. Most conclusively, the differential between dairy heifer calf price and beef steer price is the driving variable for sexed semen advantage. In terms of magnitude, a high heifer price will make Scenario 3 infeasible, resulting in large losses due to forgone opportunities that can be made by raising excess heifers for the purpose of sale. If heifer price is low, the advantage is dependent on the price of beef bull calves. The second important concept is that using sexed semen with only heifers, as in Scenario 1, has only a very small advantage to Scenario 2. Region C (Table 2.6) is larger for most variables and Region A is smaller for most variables. Scenario 3 is more difficult to compare because the some variables impact this scenario opposite of the other two scenarios. The model used has the capability to change those assumptions, both in measure and structure. Easily enough, the number of variables can be varied and how they are varied. This is a very adaptable model and begs the question of future research.

Future research specifically coming from this model could change the parameterization of the model. As noted, uniform distributions were named for all of the key input variables. If I had a sense of how those inputs varied, that would be an added benefit to the model. Also, the scenarios chosen were what I thought of as the most likely applications. Variations on the scenarios given or completely new scenarios could be suggested. A third option would be to adjust the culling rates, so that with sexed semen those rates would fluctuate allowing a producer to sell more cows under the cull decision as dairy re-sales to other farmers. This would include costs of raising an animal but with the advantage of selling her above the cull beef price.

This idea was considered here but the limitation of changing herd size and lactation did pose a problem within the model's static nature

An extension of future research to other livestock would make interesting future research. Some insights can be made from this study. One of the keys to sexed semen is the use of artificial insemination (AI). As discussed earlier, the dairy industry already extensively uses AI, and for other livestock to benefit, AI would have to become part of breeding protocol. Dairy provides a special situation because of the ability to capture two markets, where other livestock might not have that luxury. Ideally, sexed semen could be done in any animal that can be artificially inseminated; however, for some animals it may not be possible. It also depends on if sex is determined by the sperm. For example, chickens can be artificially inseminated, but sorting semen would have no benefit, because the sex of the offspring is determined by the egg. Other livestock applications really depend on if the situation is similar to dairy cattle, in that sexing of sperm is possible and the other conditions are right.

The most obvious limitation is the static nature of the model compared to the dynamic nature of the dairy farm. Simplifications in programming had to be made, and to capture the fiscal values annually, totals and aggregates for the whole year were used to quantify changes. Annual profit works well to calculate sexed semen's potential impacts, but does not capture cyclical and dynamics of a dairy farm. Even with the programming of a more dynamic model, totals and aggregates would still be required to develop a measure of standard fiscal quantity even if annual profit was not used.

Chapter 3: Technological Breakthroughs

Sexed Semen is a technology that has seen struggles and success in adoption. This thesis will explore the promises of success by combining different factors that might make a favorable environment for sexed semen adoption, most specifically, having positive returns to the producer. In this section, I discuss how ideas move into the marketplace, followed by a discussion about the specifics for sexed semen.

3.1 Innovations Combine Ideas from Pre-existing Sources

Inventions are a fascination to most people, but they also have revolutionized our way of thinking or doing. The credit is given to the inventor who brought about its rapid adoption into society. As Andrew Hargadon (2003, p 24) points out in his book *How Breakthroughs Happen,* such an intense focus on the individual undermines the process in which these inventions have been created. In 1929 Abbot Payton Usher, technology historian, wrote "Inventions find its distinctive feature in the constructive assimilation of pre-existing elements into new syntheses, new patterns or new configurations of behavior (Hargadon, 2003, p 24)." This quote suggests that the individuals tagged as inventors were only a small part of the process, if perhaps the most vital one. These individuals saw opportunities from different areas and combined them in new and unique ways.

Hargadon describes this process as a shifting of networks. Individuals, ideas and objects form new relationships very quickly and through different avenues. Strong ties form within a company or an industry where small improvements are made on old technologies. These strong ties are ones where information flows freely through individuals in an almost transparent environment where the technology exists and its applications are known inside and out. Weak ties are ones where the information is not so transparent and not accessed as easily. A clever example from Hargadon (2003) follows. Strong ties are those formed with colleagues and coworkers, news about their everyday lives travels quickly and easily through the network. A weak tie is one you have with your barista. Although you may see her every day, the information transferred between the two of you is limited. As Hargadon (2003, p 58) points out weak ties are important to you, it where the most likely to find out about a job opening or a new apartment. The application of strong and weak ties can be used outside our personal lives on a company or industry level.

A few inventions that have combined such ideas are the steam ship, a guitar, and the light bulb. The steam ship combined the steam engine and the sailing ship to create a vessel that could change global commerce (Hargadon, 2003, p 12). The guitar is relatively simple, a set of strings is attached to a base; its invention is a relatively simple one. However, look at how many different ideas have used this singular invention to produce new ones. Classical guitarists, electric guitarists, base guitarists, etc, arguably produced several different products from this one invention (Hargadon, 2003, 12). Furthermore, the production of music can be used in several manners depending on the artist's deliverance and addition of words making songs have meaning and adding more to the invention then the object. Edison, the father of invention, has in a way always done what Hargadon (2003) describes. His laboratory was created to turn out inventions by recombining existing technologies. The light bulb for instance was a combination of wires, insulation, glass bulb, and electricity, and previous ideas, all combined under the right person to launch it into mainstream. Edison's laboratory turned out hundreds on inventions all on the same principle of combining ideas, objects and people. Combining these elements has also played a significant role in the invention of sexed semen, as well as in the adoption process for commercial dairies.

Looking at sexed semen as an invention, it is easy to see it required several technologies to come into existence. Artificial insemination is a process in which animals can reproduce in a way that is controlled by humans and no longer needs the male animal to be present. Coupling the technology of artificial insemination with the idea that the dairy industry only needs females to sustain the milk production provided a significant opportunity for sexed semen to make its way into mainstream adoption. However, after creating this synthesized technology, other problems arose with efficiencies and costs. The history of sexed semen tracks the improvements made to this technology to make it more efficient and affordable, and also where I can re-apply the idea of people, objects and ideas coming together to create a rapid adoption in the future.

3.2 History of Sexed Semen: An Overview

3.2.1 Technology

"Innovation strategies rely not on breaking from the past but instead on exploiting it by harnessing the knowledge and efficiencies that reside on the elements of existing technologies (Hargardon, 2003, 12)."

In 1989 Johnson et al published an article detailing sexed semen producing live births in rabbits. Producers could choose the sex of the offspring having the potential to make large advancements both in genetics and economics. The technology used collected sperm and applied a dying process to the semen. The dying process is used to identify the difference between X and Y chromosomes based on the difference in DNA material (3.8% in cattle. The dyed semen is then sent through a flow cytometer, which reads the amount of dye with a laser. Droplets containing sperm are than charged negatively or positively for corresponding X and Y chromosomes, then collected into test tubes after falling through correspondingly charged electrical fields. The end result is a sample of semen bearing a preponderance of one kind of sex in each test tube. The semen then can be placed in straws and inseminated into a female. The offspring is than conceived by sperm that are of one sex. Previously, the difficulties had been to sort the semen in a way that the sperm was viable.

After the initial breakthrough, scientists worked steadily on creating a product that could be profitable. The biggest opportunity for this technology was seen in the dairy industry. Because dairy farmers already used artificial insemination, adoption to this area would be relatively easy for a producer, simply buying one kind of semen versus another. Additionally, the dairy industry supports itself through the demand for milk, requiring only females to be on site. It was the perfect industry for sexed semen. Smaller improvements in technology led to increasing the pressure rates to be able to sort sperm faster and more efficiently. However, sexed semen still was expensive to produce, not completely accurate, and undermined by low conception rates. Adoption was slow and lacked profitability for large operations to take on the financial burden of the sexing premium based on the extreme decrease in conception rates. Scientists needed to find the balance between costs and efficiencies.

Using the theory from *How Breakthroughs Happen*, the scientists are part of a collection of areas in which change can happen and make an invention take off in mainstream industry. Based on the history of sexed semen, identifying areas of improvement in technology is a necessary step in the adoption of sexed semen in commercial dairy operations. Here technology is identified as the first sphere of influence in finding the functional balance for widespread adoption.

3.2.2 Management

Management is the second sphere of influence, describing the individuals and producers that would be likely to use this technology. Sexed semen is a component of a specific task of allowing a producer to produce a specific sex of offspring. The producer is in charge of how sexed semen can be used to increase farm profitability. A producer also can have a large effect on the profitability depending on the farm's problem areas. These are site specific problem that are not linked to using sexed semen, but that could affect the profitability of implementation. Identifying scenarios or areas producers can change to adopt sexed semen and use it to their advantage is also necessary for widespread adoption.

Additionally, managers react to the market environment. Price ranges for inputs and outputs can dramatically affect the firm's profitability using any technology, let alone using a new one. Although the market environment cannot be changed by individuals, it's important to know its role in influencing managers' decisions. This leads to the third area of influence: the market environment.

3.2.3 Market Environment

The market environment can also play a large part in the implementation of sexed semen because of the relativity of prices. Sexed semen's premium can affect producers in different ways depending on the relative costs between inputs and outputs. Market environments where the profit gap is initially large, small or breakeven could be the difference for the implementation of sexed semen. Identifying which input and output prices are the most sensitive to a dairy's initial budget before considering sexed semen and analyzing the effects would provide situations in which producers would or would not use sexed semen technology.

Furthermore, the market can also influence how a producer implements sexed semen. Competing output prices could change the application of sexed semen to increase profitability and also increase or decrease the likeliness of its adoption. Providing the key input and output prices of the market environment, increases the understanding of management's role and its link to the environment.

3.2.4 Linking Areas of Influence

The three areas of influence all have their key roles in providing information for sexed semen adoption. However, it may be difficult to visualize. A Venn Diagram can be used as an adaptive visual model of Hargadon's idea of bringing pieces together from different areas to develop innovations. Below, a Venn Diagram is represented in three figures, as the areas that would need to synthesize and come together for the technology of sexed semen to reach widespread adoption among commercial dairies. Each circle represents an area of influence. The Figure 3.1: Region C, where all three spheres completely overlap, is the ideal condition for which sexed semen would be profitable to implement. It represents the combination and level of key components in each sphere of influence where the levels of the variables are all

appropriate for sexed semen that a change in any one variable will not cause a negative investment. The areas where there is no overlap, Figure 3.2: Region A, represent conditions where sexed semen cannot be made profitable. A change in a single variable is not enough to create a positive investment. The other figure, Figure 3.3: Region B, represent less than ideal opportunities. Areas, where two spheres overlap, represents a condition where changes in single variable could make sexed semen profitable. For example, the area where technology and market environment overlap signifies a condition where a change in a management variable could make sexed semen profitable.

3.3 Previous Studies on Commercializing Sexed Semen

Sexed semen has been seen by scientists as having great potential to help dairy farms. Early studies have focused on three major areas. Early scientific literature has looked at sexed semen's prophesized abilities in terms of science and how application could plausibly be

Figure 3.1: Region C

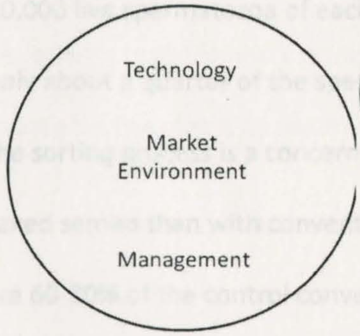


Figure 3.2: Region A

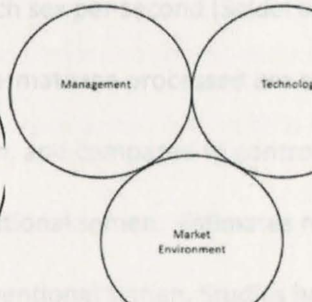
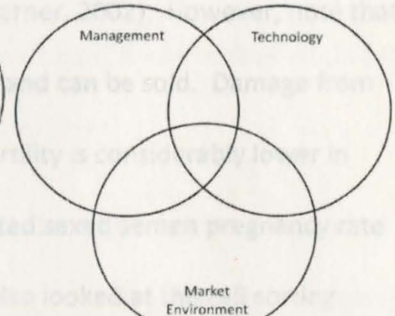


Figure 3.3: Region B



employed. Later literature focused on the actual application of sexed semen. These studies ranged from possible gains through coupling technologies such as in vitro fertilization and sexing embryos for donor cows to crossbreeding and breeding stock. The last group of literature has been published as sexed semen has become more common. It largely focuses on the impacts the dairy industry. These studies have forecast price changes, structural changes and where new research should turn.

3.3.1 Technical Abilities of Sexed Semen

In 1975 L. D. Van Vleck and R. W. Everett examined the economic value of sexed semen. It was theorized at the time that the largest gain would be due to increased intensity of selection on cows to produce replacements within the herd. Estimating the economic value as a difference in additional units of milk and comparing against conventional semen, sexing semen was found to be considerably more profitable in net value. By determining its genetic transmitting capabilities, Van Vleck and Everett determined the value sexed semen should sell for if the application was to increase milk production through genetics. Discount rates, and years of investment were taken into account; however the difference in conception rates, and the effects on days open were not.

Since then sexed semen has undergone many improvements in technology. Seidel and Garner (2002) discussed its progress and the doors that have opened for this technology. Currently, sexing can be done 85-90% accurately and can be done at a theoretical upper rate of 10,000 live spermatozoa of each sex per second (Seidel and Garner, 2002). However, note that only about a quarter of the spermatozoa processed are sexed and can be sold. Damage from the sorting process is a concern, and compared to controls, fertility is considerably lower in sexed semen than with conventional semen. Estimates reported sexed semen pregnancy rate are 60-80% of the control conventional semen. Studies have also looked at the cell sorting process as a culprit to decreased pregnancy rates. However, animals produced using sexed semen have no known abnormalities from the sexing process. The commercial application discussed in this paper is reproducing in horses and cattle. Seidel and Garner (2002) state that sexing semen is expensive largely due to inefficiencies, and high processing costs, but improvements are continually being made. As efficiencies improve, sexed semen will conclusively be applied more widely.

In 2003 Seidel et al published *Embryo Transfer in Dairy Cattle* and discussed the efficiencies of using embryo transfers and sexing semen technology. Sexed semen has been under scrutiny since its development because of the high costs in obtaining sexed sperm. The technology, however, would allow for producers to select replacements from their top cows and breed the bottom and middle of the herd to yield calves as beef crosses or bull calves for the meat market. This would improve the genetics of the herd as well as boost returns in meat market calves. Similarly, embryo transfer application also has a couple of other applications for producers. Progeny testing for cows through embryo transfer was highlighted as an efficient way to increase genetics within a herd effectively and efficiently, and also to detect undesirable recessive traits. Second, the best cows can be used for young sire programs. According to Seidel et al (2003), with traditional methods it takes 300 cows to obtain 100 bulls. With the use of embryo transfer, only 150 cows would be needed to obtain 100 bull calves and with sexed sperm even fewer. Seidel et al (2003) also notes that the genetic gains in milk production have yet to outweigh the costs associated with such procedures. Therefore, it was concluded that the most effective way is to use this technology for artificial insemination.

Moore and Thatcher (2006) discussed advances in reproduction, one of which is sexed semen. Listing its plagues as being slow to produce, expensive and riddled with poor conception rates, sexed semen is not an investment to take lightly. Strategies for using sexed semen to improve efficiencies on site and being cost effective are still being developed by commercial producers. One strategy is to use sexed semen on the first service and unsexed semen thereafter. This reduces costs and is said to generate a female calf crop of >62% at first calving. A second strategy is using in vitro fertilization programs to improve the ratio of sperm to fertilize oocytes. This second strategy alleviates the problem of slow production and low sperm numbers. Moore and Thatcher (2006) still conclude that more improvements need to be made to gain widespread use in the dairy industry.

3.3.2 Slow Commercial Adoption in Sexed Semen Initially

Although sexed semen seemed to have a lot of potential, the most cost effective ways to use it were still unclear. The following studies focused on the benefits of using sexed semen through various applications.

Hohenboken (1999) explored the applications of sexed semen on commercial dairies. Commercial dairy farmers could use sexed semen to produce replacement heifers of superior genetic quality, shortening the generation interval with the ability to choose only top females. A secondary application would be to produce male beef crossbreeds from the remainder of calves, adding more meat value to those calves. Seed stock dairy breeders, producers that breed for high quality bulls, would have the ability to produce bulls for progeny testing from a more selective group of elite dams, because fewer would be required to achieve the desired number of bull calves. Hohenboken also explored the applications as they apply strictly to beef operations, however that is outside of the scope of this research. In response to the lower conception rates, in vitro fertilization has been coupled with sexed semen. The use of in vitro fertilization guarantees fertilization without the extra costs of insemination; however, there are also risks involved in the embryo transfer as well as increasing abortion rates.

Madalena and Junqueira (2004) determined the value of sexed semen as expected net present value of progeny in sexed semen versus unsexed semen. The NPVs were based on four categories: males and females and correspondingly sale progeny or retained progeny. Decreased conception rates are a major concern for sexed semen, and profitability was found to vary proportionately to the conception rate. Madalena and Junqueira find that using sexed semen in the dairy cattle industry increases continuously with the efficiency of sexing (measured by accuracy of fertilization). Their model did not take into account situational effects such as the decrease loss in profit from less dystocia (difficulty calving) in heifers bred to have heifers or beef calves. The model was also not specific to any type of dairy. Critical assumptions of farms operations such as replacement rates, conception rates, number of lactations and lactation curves were all based on optimal and averages for the region and production level.

Wilson et al (2005) studied the synergies between sexed semen and in vitro embryo production for producing replacement heifers on a commercial dairy farm. Using oocytes from involuntarily culled cows, embryos were fertilized in vitro with sexed semen. Explanatory variables included: embryo stage synchrony of recipients, corpus luteum quality and side, amount of time the embryo was kept in straw, recipient group (cows or heifers), farm ID, GnRH treatment at embryo transfer, season, and the sire of the embryo. Backward, stepwise elimination of variables was used to find the final model of analysis. The sex ratio of sexed in vitro embryo calves was the same as with conventional sexed AI calves. The results indicated that sexed semen can be combined with in vitro fertilization to generate inexpensive replacement heifers.

3.3.3 Impacts and Usages in Sexed Semen

The following studies discuss the impacts and possible structural changes sexed semen will have on the dairy industry. It also provides insight on the direction future research should turn.

According to Weigel (2004) the crossbreeding strategy will fail in implementation for two reasons: conception rates with sexed semen in lactating cows are too low given the price of sexed semen, and the value of crossbred bull calves is small relative to purebreds when one takes into account the potential value of the milk from their dams. Weigel (2004) suggests if heifer calves are not desired from genetically inferior cows, the rational strategy would be to avoid breeding these cows, and extend their terminal lactations using BST. Because artificial insemination is widely used in the dairy industry already, breeding decisions will largely be determined by the marginal cost of sexed semen and the benefits of having the ability to choose offspring's sex.

Olynk and Wolf (2007) performed a study comparing the expected net present value of artificial insemination using sexed and unsexed semen on dairy heifers. NPV was compared using four breeding strategies: a single dose of sexed semen followed by conventional semen, 2 doses of AI using sexed semen followed by conventional semen, pure and continuous sexed semen, and lastly pure, continuous conventional semen. Based on the four strategies, cows were bred until a pregnancy rate of 90% was achieved. These were then used with twelve conception rate scenarios. The breakeven price for heifers was calculated to achieve positive NPV, where and NVP of zero would indicate the NVP equal to pure conventional sperm. The breakeven price for heifers was found to be $512.81 for pure sexed semen compared to conventional sperm; however, pure sexed semen systems are unrealistic. NPV was found to be positive only at the better conception rates for all sexed semen strategies. It was again concluded that sexed semen is held back by the increases in breeding costs, due to lower conception rates. Sexed Semen was concluded to be profitable in a limited number of scenarios due to the negative NPV.

De Vries et al (2008) studied the potential impact of widespread adoption of sexed semen technology in the dairy industry and its implication on the dairy industry structure. The following key assumptions were made: fertility of sexed semen is close to that of unsexed, sexing is 90% accurate, sexed semen from popular sires is widely available, and price is not a limitation on the adoption of sexed semen. Currently, herd turnover rate and the maximum number of replacements produced is nearly the same. Breeding is needed both to start new lactations and to replace cows, but the authors concluded with the availability of genetically competitive sexed semen the two regimes will be uncoupled and new reproductive management decisions will be needed. De Vries et al (2008) suggests that as heifer prices decrease with implementation, herd turnover rates will increase because it will be worth more to replace more cows of marginal value. It is also theorized that the cull cow prices will decrease as a result of the increased turnover rate. Milk price is also very sensitive to supply and demand, and would fall overtime as the cost of production decreases. These conclusions were based on a wide range of prices and assumptions about the market and cow performance. The breeding decision is also discussed and although recommended that heifers be used for use of sexed semen(Seidel and Garner, 2003), De Vries notes that even if 90% of heifers calved with female calves additional calves would be needed to replace all the culled cows. Currently, most of the genetic progress occurs through sire selection, with the use of sexed semen the rate of genetic change is variable. However, with use of sexed semen, genetic change is not expected to increase more than 15% of current yields (Hohenboken, 1999; Weigel, 2004; De Vries et al, 2007). De Vries et al (2008) state that no studies were available that has incorporated all aspects to determine the economic value of sexed semen.

3.4 Contribution and Significance of Research

Because none of these studies have really told producers when the conditions are right to implement sexed semen my objective is to find the technology, management and market environments that allow sexed semen to be profitable. The implementation of sexed semen requires considering all three areas in order to meet a producer's criterion for profitability. By looking at the three environments as Venn Diagrams, there is an area where sexed semen would be profitable, and there are areas where the actions of managers or technicians could make a difference. The purpose of this study is to provide producers and scientists with information.

Chapter 4: Extended Discussion about Methodology

The spreadsheet is really the driver behind the study, it controls for all parameters, determines relationships, and devised the simulation. The model spreadsheet is of one annual year. Because NPV was used as the determining feasibility key output, there are actually five model spreadsheets set up identically. The model spreadsheet is organized into four sheets. Each has a deliberate function within the model. The spreadsheet was based off on an original model started by Ettema (2007), and many of his animal science relationship parameters were used and verified by experts.

The first sheet is a variable sheet which includes control and independent variables. The variables are organized into sections. The first are variables that individuals cannot change, such as the market, or biological capabilities of the animals. Biological variables were taken from Ettema (2007) and confirmed by Seidel (2009). The market variables are the prices of the inputs and the output prices. These were all included in the sensitivity analysis, and the most sensitive to profit were chosen as key inputs, while the others were set at a typical level, also confirmed by Seidel and Wailes (2009). The second set of variables is technology variables. These were variables that Seidel (2009) suggested could be changed by scientists, such as genetic gain, price premium, accuracy, and the effects on conception rates for heifers and cows. These variables were also included in the sensitivity analysis. In the third group are variables a manager could change. They include protocols such as synchronization, heat detection, culling practices, reproduction variables, lactation groups, and variables that cue different scenarios. Many of the protocols were chosen as assumptions or characterizing a commercial dairy in the Colorado.

Reproduction management variables were suspected to have the most impact on sexed semen, and thus were included in the sensitivity analysis. As stated above only thirteen variables were chosen for key inputs to vary, but there are many more included in the spreadsheet. A copy of the variable sheet is included in the appendix as figures A.1 and A.2.

The second sheet focuses on reproduction and the cycle of the lactations through breeding. Four tables comprise all of the data for this sheet. The first table estimates the conception rates as product of lactation group, management, and the scenario. The second two tables record pregnancy results after each insemination. Each table records the number of cows pregnant per insemination, the number that need to be rebred per service, and the resulting number of actual calves born live. One table is the result using sexed semen, and the other calculates conventional values for any given scenario. A third table, included in the appendix as Figure A.5 takes the number of cows per lactation group, and calculates their average milk production per year per cow factoring in a 1% gain for the number of bull calves, genetic gain between lactation groups, genetic gain from sexed semen and the difference in milk production per lactation. This table also largely controls the difference between each year. Each separate year draws from the corresponding year to track production gains.

A third sheet calculates feed costs based on estimates of feed consumed in a total mixed ration per cwt of milk. Costs are broken down by lactation group, and calculated on the average pounds of milk produced by that lactation group. This sheet also calculates the aggregate heifer replacement labor and feed costs. Costs are stratified by age group. Heifer replacement labor and feed costs are estimated by Wailes (2009) and based on feed and labor per animal per day.

The fourth sheet was used to track the herd through the year, (as shown in the appendix as Figure A.4). Constant herd size posed quite a problem in terms of keeping lactation groups at a constant level per year. Each lactation group, had a constant number of cows culled each year to equal the lactation group for the consequent year. A backwards calculation was done based on the mortality rate, reproduction culling rates, infertility and increased to a level to so that constant herd size could be assumed. This cull rate was kept constant every simulated year to insure constant herd size as well as constant lactation size.

A fifth sheet separates the number of cows used for sexing and then is fed into the second worksheet that controls the number of sexing inseminations. Because cows were bred on a percentage basis, attributing the correct number of inseminations to sexed semen versus conventional semen needed to be separated out and tracked through inseminations, pregnancies, and rebreeds. This sheet tracks the number of rebreeds and those numbers track back to the insemination table on sheet 2.

Finally a sixth sheet (Figure A.2 in the appendix) is the partial budget combining all inputs and sheets. The budget links the variable sheet prices to the annualized numbers determined by the other sheets. Largely based on the budget used in Ettema (2007), this budget has the likely revenues and operating expenses for a dairy farm. For the different scenarios, additionally, variables that were determined to not be affected by sexing were calculated on the budget sheet. Those variables included labor, veterinary costs, and feed costs.

After the model spreadsheets were built, the simulation module was programmed into a separate data spreadsheet using a macro. The macro identified the thirteen key inputs, and placed a uniform distribution on each over the range identified in Chapter 2. Then using a random draw, a variable value was chosen and input into each of the five model spreadsheets, in the variable sheet. A network of binary variables in the variable sheet turns different scenarios on and off to capture values. Each yearly spreadsheet used the input values to calculate profit on the budget sheet. The value of the variables as well as the profit for each year and scenario were recorded into data sheet. The draws were run 8,000 times, leading to 8,000 data points for each scenario. Variables were held constant at the draw level for each scenario including the control. NPV was calculated for control, Scenario 1, 2 and 3. A difference column was calculated subtracting the control from each scenario's NPV. From this data sheet SSA was regressed over the thirteen key inputs.

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Appendix

Figure A.1: This figure represents the three groups broken down by sphere. From these groups the sensitivity analysis was done on the variables indicated with the exception of cohort size and heat detection. Key input variables are shown at the level of the last random draw.

Market				Technology			Management Decisions	
Price of	Milk	11	cwt	Premium	$20		Number of Cows	2500
Price of	Veterinary costs	60	head	Sex Ratio (sexed semen)	91%			
Price of	Veterinary costs above 18000 lbs prod.	5	cwt >18000	Conception Rates SS Cows	0.76		Genetic Gain in Milk Production	1%
Price of	Synchronisation costs (OvSynch)	13	dose	Conception Rates SS Heifers	0.66500833		Base Milk Production C1	17600
Price of	Normal Semen	15	dose	Gain genetic Production SS	107%		Age of First Breeding	14
Price of	Beef Semen	15	dose				No. of Inseminations w. New Technology	2
Price of	Bedding	32					Inseminations before Culling (H)	4
Price of	BST (Posilac)	5.8	dose				Inseminations before Culling (C)	7
Price of	Bull calf	80.19296	calf				Conception Rate Factor	0.809085
Price of	Heifer calf	160	calf				Breeding Regimes	
	Ratio	0.78205					Cows	0.65
Price of	Beef calf (Male)	200	calf				Heifers	1
Price of	Beef calf (FeMale)	120.9921						
	Weight of culled cows	1400	cow				Traditional Semen	0
Price of	Meat culled cows	0.45	lb				Sexed Semen	1
Price of	Spring heifer	1200	cow				Beef Semen	1
Price of	Cows Sold for Dairy	1100	cow				Cows Option	1
Price of	Labor	8	hour				Expansion	0%
Costs of extra days raising		2.817695	per day					
							Cohort 1 Weight	35%
Cost of	Forage	126.3301	ton				Cohort 2 Weight	28%
Cost of	Corn	4.193098	bu.				Cohort 3 Weight	37%
Cost of	Soybean meal	0.11451	lbs					100%
Cost of	DICAL	0.13	lbs				Heat Detection	100%
Cost of	T.M. Salt	0.1	lbs					

Figure A.1: This figure represents the farm and biological characteristics in the fourth catagory of grouping.

Farm Characteristics and Biological Variables		
Sex Ratio (normal semen)		50%
Days to Rebreed		28
Cull Rate (Heifers)		6%
Cull Rate (Cows)		35%
	Dairy	4%
	Beef	25%
Infertility (Heifers)		2%
Mortality (Cows)		6%
Mortality (Heifers)		2%
Mortality(Calfs from stillbirth to 12mnths)		3%
Abortion Rates (Cows)		5%
Abortion Rates (Heifers)		2%
Dystocia Risks Bull Calves (Cows)		7%
Dystocia Risks Bull Calves (Heifers)		24%
Dystocia Risks Heifer Calves (Cows)		4%
Dystocia Risks Heifer Calves (Heifers)		14%
Dystocia Risks Beef Calves (Cows)		8%
Dystocia Risks Beef Calves (Heifers)		
Loss from Dystocia Score (Cows)		$80.00
Loss from Dystocia Score (Heifers)		$103.00
Stillbirth Risks Bull Calves (Cows)		8%
Stillbirth Risks Bull Calves (Heifers)		20%
Stillbirth Risks Heifer Calves (Cows)		4%
Stillbirth Risks Heifer Calves (Heifers)		10%
Stillbirth Risks Beef Calves (Cows)		8%
Stillbirth Risks Beef Calves (Heifers)		
Dam Mortality Bull Calf (Cows)		
Dam Mortality Bull Calf (Heifers)		3%
Dam Mortality Heifer Calf (Cows)		
Dam Mortatlity Heifer Calf (Heifers)		1.5%

Figure A.2: Partial budget used for a single year.

		Total	Per Cow	Per CWT
Revenue				
	Milk	5510875.07	2204.35	11.00
	Bull Calves	16077.91	6.43	0.03
	Heifer Calves	14465.35	5.79	0.03
	Beef Calves	222074.08	88.83	0.44
	Culled Cows (Beef)	293750.00	117.50	[illegible]
	Culled Cows (Dairy)	110000.00	44.00	[illegible]
				0.00
	Dystocia Loss	[illegible]	[illegible]	[illegible]
Total Revenue		[illegible]	[illegible]	[illegible]
Costs				
	Breeding costs			
	Synchronization costs (OvSynch)	147965.27	59.18	0.30
	Normal Semen (Cows)	0.00	0.00	0.00
	Normal Semen (Heifers)	11820.35	4.73	0.02
	Sexed semen	151975.32	60.79	0.30
	Beef Semen	95026.30	38.01	0.19
	Total Breeding Costs	[illegible]	[illegible]	0.81
	Veterinary costs			
	Per head for 13000lbs of Milk	150000.00	60.00	0.30
	Above 13000 lbs prod. (per 3000lbs)	247188.73	98.88	0.49
	Total Veterinary Costs	397188.73	158.88	0.79
	Replacement Heifers (to first calving)	[illegible]	[illegible]	[illegible]
	Cow Feed Costs			
	C1	1105484.92	[illegible]	[illegible]
	C2	1014695.36	[illegible]	[illegible]
	C3	[illegible]	[illegible]	[illegible]
	Total Feed Costs	[illegible]	[illegible]	[illegible]
	Labor Costs			
	Milking	261800.00	[illegible]	[illegible]
	Feeding	320380.00	[illegible]	[illegible]
	Cow care	240000.00	96.00	[illegible]
	Other	200000.00	80.00	[illegible]
	Total Labor Cost	[illegible]	[illegible]	[illegible]
	Other Costs			
	Bedding	32.00	[illegible]	[illegible]
	DHIA	22.00	[illegible]	[illegible]
	Milk Hauling and marketing	150.00	[illegible]	[illegible]
	Supplies	35.00	[illegible]	[illegible]
	Utilities, repairs, fuel	25.00	[illegible]	[illegible]
	Total Other Costs	[illegible]	[illegible]	[illegible]
Total Costs		[illegible]	[illegible]	[illegible]
	Profit	-570454.40	[illegible]	[illegible]

		Total	Per Cow	Per CWT
Budget				
Revenue		Total	Per Cow	Per CWT
	Milk	5510878.07	2204.35	11.00
	Bull Calves	16077.91	6.43	0.03
	Heifer Calves	14443.35	5.78	0.03
	Beef Calves	222074.68	88.83	0.44
	Culled Cows (Beef)	393750.00	157.50	0.79
	Culled Cows (Dairy)	110000.00	44.00	0.22
				0.00
	Dystocia Loss	-19473.26	-7.79	-0.04
Total Revenue				
		6247750.75	**2499.10**	12.47
Costs				
	Breeding costs			
	Synchronisation costs (OvSynch)	147945.27	59.18	0.30
	Normal Semen (Cows)	0.00	0.00	0.00
	Normal Semen (Heifers)	11820.32	4.73	0.02
	Sexed semen	151875.42	60.75	0.30
	Beef Semen	94026.50	37.61	0.19
	Total Breeding Costs	**405667.51**	**162.27**	**0.81**
	Veterinary costs			
	Per head for 18000lbs of Milk	150000.00	60.00	0.30
	Above 18000 lbs prod. (per 3000lbs)	247188.71	98.88	0.49
	Total Veterinary Costs	**397188.71**	**158.88**	0.79
	Replacement Heifers (to first calving)	1437303.27	574.92	2.87
	Cow Feed Costs			
	C1	1165484.32	466.19	2.33
	C2	1014695.36	405.88	2.03
	C3	1385695.97	554.28	2.77
	Total Feed Costs	**5003178.93**	2001.27	**9.99**
	Labor Costs			
	Milking	251800.00	100.72	0.50
	Feeding	320000.00	128.00	0.64
	Cow care	240000.00	96.00	0.48
	Other	200000.00	80.00	0.40
	Total Labor Cost	**1011800.00**	**404.72**	2.02
	Other Costs			
	Bedding	32.00	0.01	0.00
	DHIA	22.00	0.01	0.00
	Milk Hauling and marketing	156.00	0.06	0.00
	Supplies	85.00	0.03	0.00
	Utilities, power, fuel	75.00	0.03	0.00
	Total Other Costs	**370.00**	**0.15**	0.00
Total Costs		6818205.15	2727.28	13.61
	Profit	-570454.40	-228.18	-1.14

Figure A.3: Herd Tracking. This table provides the annual tracking of the herd. Details on how many cows were culled for each group as well as the type of sale issued to remove the animal from the herd.

Group Weights	35.00%	28.00%	37.00%	100.00%	
Year	**C1**	**C2**	**C3**	**Total Cows**	**Number of Heifers Needed**
Annually	875.00	700.00	925.00	2500.00	
Culled Cows	175.00	150.00	550.00	875.00	927.5
Percent Culled by Lactation	7.0%	6.0%	22.0%	35.0%	
Culled For:	Dairy	Beef	Died	Total Culled Annually	
	100	625	150	875	

Figure A. 4: Milk Production Records. This table was used to track the aggregate milk production per lactation group from year to year, taking into account increases in milk production year to year as well as genetic gains of the entire herd annually. Production units used for revenue stream were the aggregate annual production reported using the additional boost associated from having bull calves.

Milk Production						
	Gains from Lactation	0.18	0.07			
Year	C1	C2	C3	Total	w.Bull Calves	Annual Gains
1	17600.00	20562.38	21783.90	19977.51	20039.55661	
2	17776.00	20768.00	22001.74	20177.28	20239.95218	1.01
3	17966.80	20975.68	22221.76	20383.62	20446.93132	1.010226266
4	18159.66	21200.83	22443.98	20596.38	20660.35257	1.010437813
5	18354.58	21428.39	22684.89	20817.46	20882.11677	1.010733805
6	18551.59	21658.40	22928.38	21040.91	21106.26134	1.010733805
7	18750.72	21890.88	23174.49	21266.76	21332.81183	1.010733805
8	18951.99	22125.85	23423.24	21495.03	21561.79407	1.010733805
9	19155.42	22363.35	23674.66	21725.76	21793.23417	1.010733805
10	19361.03	22603.39	23928.78	21958.96	22027.15849	1.010733805