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An Economic Analysis of Factors Affecting Pre-Weaned Dairy Calf Growth and Profit Optimization in Dairy Calf Operations

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AN ECONOMIC ANALYSIS OF FACTORS AFFECTING PRE-WEANED DAIRY CALF GROWTH AND PROFIT OPTIMIZATION IN DAIRY CALF OPERATIONS

by

Vincent T. Hess

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ABSTRACT

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by

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This study was an extension of a study submitted in April 2014 by Sheldon D. Holt entitled “Ambient Temperature, Calf Intakes, and Weight Gains on Preweaned Dairy Calves”.

A major component in a profitable dairy operation is the raising of female calves as replacement heifers; but since no direct income is generated by calf raising alone, it is often overlooked as a potential profit area on a dairy farm. Calf management practices that ultimately impact milk productivity and reproductive performance during a heifer’s lifetime begin at birth. This study examines the effects of weather conditions and ambient temperature on dairy calf growth, measuring specifically calf weight. Other factors included in the study are seasonal change, hip height, calf starter intake, and days since birth. Of primary concern is how calf starter intake affects production costs.

The cost of calf starter is one of the main contributors to total production cost in raising dairy calves. Since the amount of starter intake consumed by the calves in this study was measured by Holt (2014), a cost analysis can be performed using these data. Therefore, the first two objectives of this study are to 1) develop a model which minimizes cost of starter feed (which is a variable controlled by the dairy producer) and 2) use the model developed under objective 1) to find the breakeven point (where the cost of an input is less than or equal to the value gained from that input) and conduct sensitivity analysis with respect to this point.

Although an analysis was performed on the data at the close of its collection in 2014 by S.D Holt, there are several econometric issues that were not adequately addressed before these analyses were performed. The following problems have been found in the data: functional form, multicollinearity, heteroskedasticity, and serial correlation. In order for interpretations and predictions based on these data to be valid, the last two objectives of this study are to 3) define in detail the econometric problems that existed in Holt's study and 4) find and implement solutions to econometric problems that existed in that study.

(103 pages)

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Vincent T. Hess

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In order for dairy producers to maximize profit in their operations, or minimize cost given the competitive nature of milk production, it is imperative that great effort be put forth in raising and maintaining healthy dairy animals. To run a profitable operation, dairy producers must determine which operation methods are most efficient for their business and then implement those methods on their farm. As technology and research in dairy production improve, dairy producers must know if and when to adopt these new methods in order to increase dairy production and improve overall animal health.

This study examines the effect of calf starter intake on calf growth, specifically measuring calf weight. How calf starter intake affected production costs was also examined. This information will be helpful for dairy producers because the inputs used to raise dairy calves, such as feed and labor, are very expensive. Through the application of the findings in this study, the efficiency in growth from birth to weaning can be increased in order to minimize dairy producers' costs, thus maximizing their profits.

Other factors included in the study were seasonal change, hip height, days since birth, overall health score, and weather conditions. Weather conditions, including high or low ambient temperature, is one factor that has been proven to cause thermal (heat/cold) stresses negatively affecting dairy animal health.

> Thermal stress is a major cause of production losses in the dairy and beef industries. Dairy animals are more heat sensitive as average milk yield has increased. During thermal stress physiological and biochemical changes occurs in the animal body which directly or indirectly affect the production. (Ganaie, A.H. et al., 2013)

While a fair amount of research has been conducted on the impact of extreme ambient temperature on adult dairy cows, little has been done on dairy calves. Because a dairy heifer's ability to produce milk over her lifetime depends highly on her rate of growth from birth to first calving, a profitable dairy operation will ensure that its calves experience as little thermal stress as possible.

This study is an extension of a study submitted in April 2014 by Sheldon D. Holt entitled "Ambient Temperature, Calf Intakes, and Weight Gains on Preweaned Dairy Calves." His thesis was done in partial fulfillment of the requirements for the degree of Master of Science in Animal, Dairy and Veterinary Science at Utah State University (Holt, S. D. 2014).

OBJECTIVES

The overall purpose of this study was to identify how a dairy producer can minimize cost in raising dairy calves, thus maximizing profits. On a more specific level, the objectives were to:

1) Develop a model which minimizes cost of starter feed (which is a variable controlled by the dairy producer);

2) Use the model developed under objective 1) to find the breakeven point (where the cost of an input is less than or equal to the value gained from that input) and conduct sensitivity analysis with respect to this point;
3) Define in detail the econometric problems that existed in Holt's study;
4) Find and implement solutions to the econometric problems that existed in that study.

By fulfilling these objectives, dairy producers can more fully understand to what extent the factors included in the study are affecting dairy heifer calf growth. The costs associated with a calf raising operation and how to minimize these costs, thus maximizing profits, will also be understood more clearly. By defining the econometric issues that exist in the study and finding and implementing solutions to these issues, the conclusions reached will be more reliable. The point of cost minimization will give dairy producers a more exact answer to questions such as, "When is the best time to wean my calves?" and "What is the cost of calf starter to raise my calves from birth to the time of weaning?"

CHAPTER II

LITERATURE REVIEW

The first two objectives of the study are to 1) develop a model which minimizes cost of starter feed (which is a variable controlled by the dairy producer) and 2) use the model developed under objective 1) to find the breakeven point (where the cost of an input is less than or equal to the value gained from that input) and conduct sensitivity analysis with respect to this point. Since an understanding of production economics is helpful in making decisions related to cost in an operation, the following section explains the development of production economics and its application in the agriculture industry.

PRODUCTION ECONOMICS

Beginning in the early 1950s, as business decisions on farm operations began to be more analytically and scientifically based, economists began the development of formal theories of production. These economists were working to answer three basic production questions: 1) "How much to produce?", 2) "How to produce it?", and 3) "What to produce?" New theories regarding optimal output and quantities of resources employed for production were tested, influencing firms' decisions. As these theories were more widely used and accepted, production economics emerged as a new field of study in economic theory.

The production function, formulated during this time period of intellectual advancement, demonstrates the transformation of the four primary resources available to a farming operation (labor, land, capital, and technology) into a usable product.

> The production function portrays an input-output relationship. It describes the rate at which resources are transformed into products. There are numerous input-output relationships in agriculture because the rates at which inputs are transformed into outputs will vary among soil types, animals, technologies, rainfall amounts, and so forth. Any given input-output relationship specifies the quantities and qualities of resources needed to produce a particular product. (Doll, J. P., & Orazem, F. 1984)

The production function became a widely accepted tool in studying "production" economics and proved useful in helping optimize input and output quantities. A production function can be symbolically written as:

$$Y = f(X_{1,} X_{2,} X_{3,} \dots, X_N) \tag{1}$$

Output is represented by Y and $X_{1,} X_{2,} X_{3,} \dots, X_N$ are different inputs that combine to produce output Y. The functional symbol "f" represents how the different inputs are transformed into an output. There will be a unique output with each variation of inputs. It is also important to note that each X can be a fixed or variable input.

There are many concepts that can be derived from a simple analysis of the production function that are useful to any manager involved in production. Marginal productivity, one of these concepts, is determined by simply taking the partial derivative of the production function with respect to the specific input that is being scrutinized:

$$f_{X_k} = \frac{\partial Y}{\partial X_k} \tag{2}$$

More simply stated, the change in the amount of output that is caused by a change in the amount of input is known as the marginal physical product (MPP) of that input, holding all other input amounts constant. This allows an economist to study the impact of each input individually. As the level of input is increased beyond some point, the law of diminishing returns becomes apparent.

> The law of diminishing returns is fundamental to all of production economics. The law is misnamed. It should be called the law of diminishing *MARGINAL* returns, for the law deals with what happens to the incremental or marginal product as units of input or resource are added. The *law of diminishing marginal returns* states that as units of a variable input are added to units of one or more fixed inputs, after a point, each incremental unit of the variable input produces less and less additional output. (Debertin, D. L. 2012)

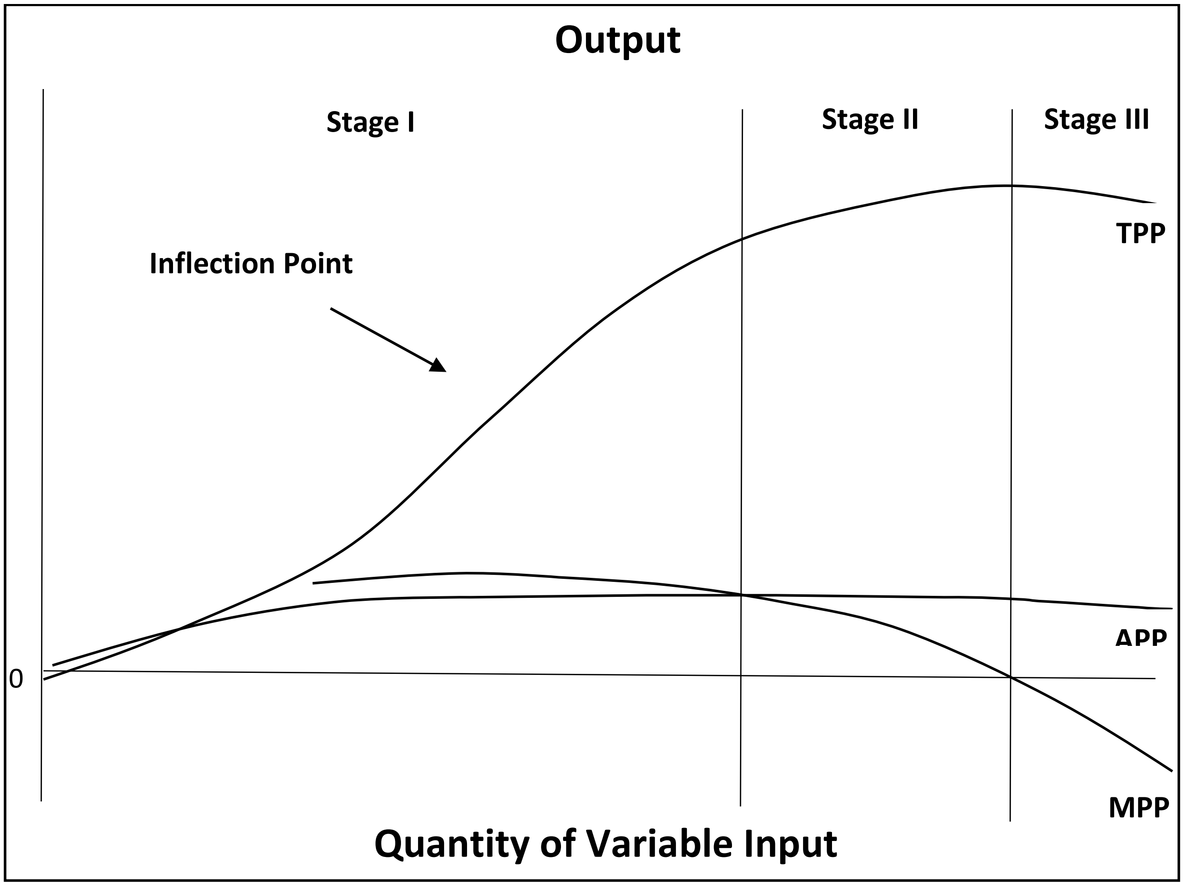
As a manager of production, focusing on marginal physical product (MPP) instead of focusing on average physical product (the total amount of output divided by the total amount of input or APP) is important because it allows the manager to look at the effect of each input as it is added sequentially and, therefore, make changes to variable inputs with more accuracy and confidence.

This idea can be further explained by referring to the concept of returns to scale (the rate by which output changes if all inputs are changed by the same proportion). As production begins initially, it is assumed that increases in each of the inputs by the same proportion will result in increases in output by larger proportions. Thus, increasing returns to scale (when output increases by more than the proportional change in inputs) are realized and output elasticity (E_O, the percentage change in output divided by the percentage change of an input) is greater than one.

$$E_O = \frac{\%\Delta Y}{\%\Delta X_k} \tag{3}$$

As the amount of input used in production continues, a point will be reached where the proportional increase in output is less than the proportional increase in input; output elasticity is less than one; and there are decreasing returns to scale (output is decreasing by more than the proportional change in inputs). Also, the production process will at some point reach a maximum where increases of variable inputs will not increase output and output elasticity can become zero or even negative. This is shown graphically in *FIGURE 1*, where total physical product (TPP), average physical product (APP), and marginal physical product (MPP) are represented.

Figure 1 Three Stages of Production



Stage I of the production function includes levels of input from zero units up to the point of use where MPP is equal to APP. The region from the point where MPP is equal to APP to the point where the production function reaches its maximum, and MPP is equal to zero, represents stage II of the production function. Stage III of the production function includes the region where the production function is declining and MPP is negative.

The classical production function, shown in *FIGURE 1*, can be divided into three stages of production, designated by Roman numerals I, II, and III. Stage II is often referred to as the rational stage of production or economic region of production. This means that rational farmers, who have the goal of maximizing profits and/or minimizing cost, will operate within region II.

Stages I and III are considered irrational stages of production. This is because a rational farm manager would never choose to produce with levels of input within these regions. An irrational farmer would be one who chooses a goal inconsistent with the maximization of net returns or profit, or minimizing cost.

There are key relationships between total physical product (TPP), average physical product (APP), and marginal physical product (MPP) that are important for production managers to understand. First, TPP is simply the total output (Y).

$$TPP = Y \tag{4}$$

APP is found by dividing the total amount of the output (Y) by the amount of the variable input in question (X_k), while all other variable inputs are held constant. APP measures the average rate at which an input is transformed into a product or output.

$$APP = \frac{Y}{X_k} \tag{5}$$

APP is also a measurement of the efficiency of the variable input. MPP is the change in output resulting from a unit change in one of the variable inputs, holding all other variable inputs constant. MPP measures the amount that total output increases or decreases as one variable input increases and represents the slope of the production function. Conceptually, average MPP is calculated by dividing the change in output caused by or resulting from the incremental change of an input, i.e., a chord connecting two points of a straight or curved production function on a two-dimensional graph.

$$Avg.MPP = \frac{\Delta Y}{\Delta X_k} \tag{6}$$

The exact MPP for a very small change in input use can be calculated by taking the first derivative of the production function with respect to the variable input being considered.

$$MPP = \frac{dY}{dX_k} \tag{7}$$

There are several key points regarding the relationship between TPP, MPP, and APP. As long as TPP is increasing at an increasing rate, MPP and APP are also increasing. However, once TPP begins to increase at a decreasing rate MPP has reached a maximum and begins to decline. The point where MPP is at a maximum is known as the inflection point. This is where the function changes from increasing at an increasing rate to increasing at a decreasing rate. In other words, the inflection point marks the end of increasing marginal returns and the beginning of diminishing marginal returns. The function will eventually reach a point where TPP is at a maximum (MPP will be zero at this point) and the function begins to turn downward. If there is an increase in the use of variable input beyond this point, then there will be a decrease in TPP. This could occur, for example, if a farmer uses so much fertilizer on a field that it negatively impacts crop growth. APP will begin to decline once MPP is less than APP, because at this point the gain in output from each additional unit of input is becoming less and less, bringing down the overall level of APP.

Returning to the three basic production questions mentioned in the first paragraph of this section (i.e., 1) “How much to produce?”, 2) “How to produce it?”, and 3) “What to produce?”). The question of “How much to produce?” deals with finding the input level and output level that maximizes profit. The profit maximizing level of an input occurs where the value of marginal product (VMP) of that input is less than or equal to the marginal factor cost (MFC) of that input. Thus, the most efficient level of use of an input is the point where the value of additional output received from an additional unit of input is just greater than or equal to the cost of that additional unit of input (Wilde, R. A., 1991).

The answer to the second question, “How to produce it?”, is related to input substitution. The practice of exchanging one input for another without altering total output is known within the economics profession as the marginal rate of technical substitution (MRTS). In production, various combinations of different inputs will produce a given amount of output. An isoquant is a curve representing equal quantities of output, with each point on the line representing a different combination of two outputs. Moving along this line, the amount of output will remain the same but the proportions of the two inputs will vary. There is also an isocost line which includes all possible combinations of labor and capital (or other inputs) that can be purchased for a given total cost.

The goal of a farming operation is to find the combination of inputs that produces the profit maximizing (and cost minimizing) level of output. This can be done using the MRTS and the price ratio. MRTS is calculated by dividing the MPP of the second input by the MPP of the first input.

$$MRTS = \frac{MPP_{X_2}}{MPP_{X_1}} \tag{8}$$

The price ratio is calculated by dividing the price of one unit of the second input by the price of one unit of the first input.

$$Price\ Ratio = \frac{P_{X_2}}{P_{X_1}} \tag{9}$$

In order to find the least-cost combination of inputs, simply set the MRTS ratio and the ratio of prices equal to each other,

$$\frac{MPP_{X_2}}{MPP_{X_1}} = \frac{P_{X_2}}{P_{X_1}}. \tag{10}$$

At this point the cost of adding the new input is equal to the productivity received from adding the new input, making this the least-cost combination of inputs for the farming operation. Technically, at this point the slope of the isoquant line equals the slope of the isocost line.

The third question, “What to produce?”, is applicable for a farmer who has several different options of output to produce; for example, a farmer who is able to grow several different kinds of crops. In dairy production questions like “should I produce my own hay and grain as output and in what combination?” can be answered by using a production possibilities curve which shows all the possible combinations of different outputs that can be produced using a limited resource base. Any point on the production possibilities curve indicates the maximum output combination from the given inputs. If the output of one product is increased, it will force a reduction in the amount of output of the other product. The marginal rate of product transformation (MRPT) is this rate at which the production of one good must be decreased in order to produce a single marginal (unit) of another good. The slope of the production possibilities curve measures the rate at which this occurs.

CALF HEALTH

The information in the production economics section above provides guidelines for making decisions in farming operations as they relate to production and cost. These guidelines also help in explaining the importance of the first two objectives in the study which are to 1) develop a model which minimizes cost of starter feed (which is a variable controlled by the dairy producer) and 2) use the model developed under objective 1) to find the breakeven point (where the cost of an input is less than or equal to the value gained from that input) and conduct sensitivity analysis with respect to this point. An understanding of the relation between calf health and minimizing cost in dairy calf operations is also important, since healthy dairy calves require less labor and inputs than those who suffer from illness. Health also affects the production ability of an animal, thus affecting the profitability of the dairy operation.

A major component in making a dairy operation profitable is raising calves and replacement heifers; but since no direct income is generated by calf raising, it is often overlooked as a potential profit area. Producing high quality replacement heifers at minimum cost will ultimately increase dairy operation profits. In order to reach this objective, there must be optimal care of the animal from the moment she is born. "Recognition that events in early life can have significant long-term impacts on overall growth and maturation of the animal underscore the importance of properly caring for neonates and young calves" (Heinrichs, A. J. et al., 2005). Calf management practices that ultimately impact milk productivity and reproductive performance during a heifer's lifetime begin at birth. Some of the main factors that affect growth during the first several weeks of a calf's life include total milk intake, total calf starter intake, availability and consumption of fresh water, and weather related factors, such as daily and nightly average ambient temperature.

Newborn calves are born with no passive immunity, thus they should receive colostrum (the first milk secretion from the mother cow after giving birth, extremely rich in antibodies) as soon after birth as possible in order to help build immunity. Since newborn calves often will not consume enough colostrum by nursing from a bottle, an esophageal feeder, which is inserted through the calf's mouth and down its throat reaching directly into the stomach, is used to ensure that they receive an adequate amount of colostrum. Calves are able to absorb immunoglobulins (a protein produced by plasma cells that is used by the immune system to identify and fight pathogens such as bacteria and viruses) from colostrum for a limited time after birth, and little absorption is possible beyond 24 hours. This is instrumental in supplementing the calf's immunity and helps in preventing scours.

On most dairy operations the feeding of milk twice daily, either by bottle or by bucket, is the norm. This usually results in the calves being underfed, encouraging them to consume starter grain in larger amounts. The early consumption of calf starter is extremely important in a dairy calf operation.

> When dairy calves are born, they are essentially monogastrics or simple stomached animals with a non-functioning rumen and reticulum. They rely on the nutrients supplied from milk for their nutrition . . . Putting a calf on starter soon after birth will give them a good start toward a well-developed rumen. (Bekebrede, K., Amaral-Phillips, D. 2014)

Also, the cost per pound of weight gain for a calf with a simple stomach on a dairy operation is usually substantially larger due to costs associated with feeding milk. The cost per pound of weight gain for a weaned calf who has a developed and functioning rumen will normally be decreased because of decreased labor costs associated with feeding forages and grain. Simply stated, calf starter is used to help calves transition from the milk-feeding period to the dry-feeding period as quickly as possible. It is important that the calf starter be palatable and nutritious.

Providing free access to clean, fresh water is also an important factor in raising healthy dairy calves. Calves should be given water to drink, in addition to what they get from the milk they are drinking. “Water is the most essential and cheapest ingredient in any livestock feeding operation. Unfortunately, its importance is often overlooked” (Lang, B., 2010). Water is an aid in the development of the rumen and the digestion of calf starter, allowing for earlier weaning. A research trial comparing the performance of calves receiving free choice water (fresh water made available for consumption at all times) versus no water showed calves that received free choice water, starting from birth to 4 weeks of age, had a higher daily weight gain, consumed more calf starter, and had fewer days with scours than those not receiving free choice water (Bovine Alliance on Management & Nutrition [BAMN], 2003). The amount of water a calf needs depends on factors like ambient temperature, humidity, and the dry matter content of the diet.

A common concern when raising dairy calves is, "When is the best time to wean dairy heifer calves?"

> Latest estimates of average weaning age in the United States indicate that 70% of calves are weaned at 7 weeks of age or later. In addition, 25% of farms surveyed said they weaned calves at 9 weeks or later. Considering that calves with adequate rumen development can be physiologically ready for weaning as early as 3 weeks of age, many farms have a significant opportunity to reduce age at weaning and save money and time spent on calves. (Kehoe, S. I., Dechow, C. D., and Heinrichs, A.J. 2007)

Given the large range of weaning age, there are obviously differing opinions among dairy producers on the best answer to this question. The most scientifically supported answer is that a calf should be weaned when they begin consuming about 2 pounds of calf starter grain per day for three or more consecutive days (Kehoe, S. I., Dechow, C. D., and Heinrichs, A.J., 2007). According to the Dairy Calf and Heifer Association Gold Standards, a Holstein calf's weight should double somewhere between 24 hours and 60 days of age. Ideally the doubling of calf birth weight should occur before weaning (www.calfandheifer.org). The reasoning behind weaning a calf based on calf starter consumption goes back to the importance of the calf successfully developing the rumen early, in preparation for dry feed consumption.

> Calves can be successfully weaned when adequate rumen development has occurred. The rumen and reticulum are not fully developed at birth. In fact, liquid feeds are shunted past the reticlorumen by the esophageal groove. At this time the abomasum is the primary compartment of the stomach. By the time of weaning, the rumen must have developed enough to take part in the digestive process. (Jenny, B. F. 2009)

In order to minimize unwanted stress on the calf, weaning should be done gradually, lowering the likelihood of sickness. One example of minimizing stress on calves when weaning is to gradually decrease the amount of milk given to them each day instead of discontinuing the feeding of milk abruptly. The minimization of stress is imperative since future productivity is heavily impacted by calf health from birth until puberty.

Environmental Factors Affecting Calf Health

Environmental factors have a great impact on the health and growth of dairy calves. Weather, e.g., if too hot or too cold, causes calves to use high amounts of energy to maintain their core body temperature. This energy use reduces the amount of energy used for growth, and will negatively affect calf health if not countered in some way. Because calves are given small amounts of milk or milk replacer to encourage the consumption of higher quantities of calf starter, they may not receive sufficient amounts of energy and protein during hot or cold ambient temperatures to stimulate rumen development and sanction early weaning. The rate and sufficiency of this food conversion are drastically affected by the thermal environment, making climatic factors in general important to dairy producers.

Thermal environment (the temperature of one's surroundings) is a major climatic factor affecting animal production, especially when described in terms of effective ambient temperature, i.e., a combination of air temperature, radiation, wind, precipitation, and humidity. For example, the air temperature may be very cold outside, but a calf housed in a clean, dry hutch bedded with straw may have a thermal environment that is several degrees warmer than the effective ambient air temperature outside. Variations in season and differences in geographical location lead to variability in thermal environment. When faced with wide differences in effective air ambient temperature, livestock will alter energy intake, energy expenditure, and energy stored as product (i.e. milk, meat, etc.) to compensate for changes in effective ambient air temperature. An animal will change its rate of performance – rate of growth, rate of reproduction, or any other desired function – and efficiency of converting feedstuffs and water into animal product. "A basic understanding of the relationship between animals and the thermal environment is necessary to assess the environment's impact on livestock performance" (Ames, D. 1980). Since young animals are more sensitive to changes in effective ambient temperature, this basic understanding is extremely important when raising dairy calves.

All homeothermic animals work to maintain a constant internal body temperature, regardless of their external environment. Each of these animals has a range of temperatures where they feel most comfortable called the thermoneutral zone (TNZ). TNZ is defined as ". . . the range of temperature within which the animal uses no additional energy to maintain its body temperature" (Quigley, J., 2001). TNZ can also be defined as the range of environmental temperature over which the body temperature is normal and remains normal while sweating and panting do not occur and heat production remains at a minimum (i.e. the zone of minimum thermal regulatory effort) (Ames, D., 1980). The TNZ of a calf aged one month or less is between 50°F and 78°F (10.0°C and 26.6°C), while a calf who is aged one month or more has a TNZ range between 32°F and 78°F (0.0°C and 26.6°C) (Holt, S. D., 2014). Since these temperature ranges are quite narrow, it may prove difficult for a producer to maintain an effective ambient temperature for his calves that falls within these ranges. It is important to understand how a calf will react when the temperature goes beyond its TNZ, so that changes can be made by the producer to provide an environment where the calf can be as comfortable as possible, thus minimizing the amount of stress on his calves.

Heat Stress

When the ambient air temperature goes above a calf's TNZ, the calf must move heat from its body in order to reduce heat stress caused by high temperatures.

> The term heat stress is used widely and rather loosely, and may refer to the climate, climatic effects on the cow, or productive or physiologic responses by the cow. Lee (1965) presented a definition of stress often used by physiologists, in which stress denotes the magnitude of forces external to the bodily system which tend to displace that system from its resting or ground state, and strain is the internal displacement from the resting or ground state brought about by the application of the stress. (West, J.W. 2003)

The amount of research conducted on heat stress affecting mature dairy cow productivity is extensive, while heat stress affecting dairy calves is a topic much less researched. For this reason, the majority of the following findings are from studies conducted using adult cattle as subjects and not calves.

The heat stress indices used to measure heat stress are extensive, ranging from the simple measurement of air temperature to those indices that provide a weighted estimation of factors, like high ambient temperatures, high direct and indirect solar radiation, wind speed and humidity (Silanikove, N. 2000). The movement of heat from a calf's body, in order to reduce this stress, can happen in three different ways: radiation, evaporation, or conduction.

Radiation is the transfer of heat from one object to another without the two objects ever touching. Heat can radiate from the wall of the hutch to the skin of the calf, for example; even if the calf and the wall do not make contact. During very hot weather, radiation is one technique a calf will use in order to stay cool. Blood vessels will naturally dilate to increase blood flow and bring heat to the surface of the skin, where it will radiate from the body. The evaporation of sweat is another way a calf will move heat from its body during hot weather. When environmental temperatures are at their highest, evaporation is the primary mode of heat movement from the body. This technique can become less effective in environments with high humidity because the rate at which the sweat evaporates will decrease significantly. In very hot weather calves may also pant, causing evaporation to occur through heavy breathing. Conduction is when heat is transferred from one surface to another while the surfaces are in contact with each other. This normally accounts for a small amount of heat loss in calves, except for when the calf lies on a very cold floor. An observant dairy producer will be alert to signs of heat stress in his calves and take action to counter the negative impact of high temperatures.

Heat is a major constraint on animal productivity and has shown negative impacts on growth, milk production and reproduction as a result of changes in biological functions. (Silanikove, N., 2000) There are temperature sensitive neurons located throughout the animal's body which send information to the hypothalamus (the part of the brain responsible for the body's temperature control and regulation), which invokes numerous physiological, anatomical or behavioral changes in the attempt to maintain heat balance (Curtis, S. E. 1983). Dairy cows, during heat stress, will show a decrease in activity in general, decreased feed intake, an increased respiratory rate, and increased peripheral blood flow and sweating. Since a main component of milk production is related to the amount of feed a cow consumes, heat stress is a big concern for dairy producers because it inhibits the cow's lateral appetite center (located in the hypothalamus), thus lowering milk production. So, not only is the physiologic status of the cow negatively impacted by heat stress, but the dairy producer's profits are also negatively affected.

Cold Stress

Cold stress in dairy animals, though seemingly less often a problem than heat stress in the dairy industry, should also be a concern for a dairy producer who wants his farm to be profitable. Cold stress occurs in an animal when the ambient temperature drops below the lower critical value of its TNZ. Just like heat stress, cold stress also negatively affects the overall welfare of an animal, lowering production and profitability of the dairy farm. Since a calf, when considering its body mass, body surface area, and amount of body insulation, is much more exposed to the elements than adult cattle, its lower critical TNZ value will be much higher causing it to be much more sensitive to cold temperatures. Cold air temperatures, coupled with excessive wind and/or humidity, are common weather related cold stressors and often are contributors to reduced survival in young and newborn calves. Newborn calves are especially sensitive to the effects of cold exposure because their thermal defense and heat conservation mechanisms are not fully developed.

> Factors which may enhance excessive loss of body heat by calves include a relatively high ratio of body surface to body mass, thin skin, small quantity of subcutaneous fat, poor cutaneous vascular control and evaporative heat loss from the wet skin at birth. (Olson, D. P. et al., 1980)

Calves that are born in the winter or early spring are often exposed to critically low temperatures during their first weeks of life. For neonatal dairy and beef calves, the lower critical temperature is generally accepted to be 50°F (10°C). The lower critical temperature decreases with age: a three week old calf will have a lower critical temperature of 46°F (8°C), for a one month old it is 32°F (0°C), and for a three month old calf it is 7°F (-14°C) (Holt, S. D., 2014). A study conducted by Godden et al. (2005) reveals the negative effects of winter calving on dairy calf health. Of the 438 calves included in the study, those that were born during the winter months had a morbidity rate of 52% where calves born in the summer months had a morbidity rate of 13%. The mortality rate for calves born in the winter was 21% compared to 3% for those born in the summer. While temperatures below a calf's TNZ are shown to increase morbidity and mortality rates in calves, the calf's nutrition also plays a vital role in calf rearing during colder months.

Calves born in the winter will consume more calf starter than those born during warmer months, suggesting that the extra energy intake by the winter calves is necessary in order to satiate an increased thermal demand imposed by a colder environment. It may prove difficult to ensure nutritional sufficiency of calves during periods of cold, who are still in the preruminant or rumen development period of life, because the requirements for temperature regulation are greatly increased.

Methods of Controlling Environment for Dairy Calves

"The ability to regulate temperature is an evolutionary adaptation that allows homeotherms to function in spite of the variation of the ambient temperature" (Pennisi, P. et al. 2010). As was discussed earlier, dairy calves will naturally use methods to cope with temperatures above or below their TNZ (i.e. evaporation by sweating during hot temperatures and increased calf starter intake during cold temperatures). There are also methods that dairy producers can use, that go beyond biological and environmental factors, to contribute to the mitigation of these stresses.

Housing is one of the most vital factors in creating a temperature controlled environment for dairy animals. Metal roof structures, shades, sprinklers, and fans have been used to reduce the thermal load of cattle during periods of elevated ambient air temperatures (Holt, S. D., 2014). Physical protection with artificial or natural shade presently offers the most immediate and cost-effective approach for enhancing the productive and reproductive efficiency of animals. In many cases, the provision of shade may be the most economical solution of reducing high heat load. It is suggested that a well-designed shade structure should reduce the total heat load by 30-50%. Of course, the amount of shade needed depends on the type and age of the cattle (Sejian, V., & Gaughan, J. 2015). Protective structures are also an effective way of mitigating cold stress, often providing an effective ambient temperature several degrees warmer inside the structure when compared to effective ambient temperature outside of the structure.

Dairy calves are most often housed in hutches during the first several weeks of life. Hot temperatures during the day will heat the outside surface of the calf hutch by solar radiation, causing the temperature inside the hutch to increase significantly. Placing calf hutches in a shaded area is one way a producer can reduce the heat load for his calves. The use of shade over calf hutches decreases the rise in hutch temperature, ameliorates heat stress, and improves the thermal status of the calf (Holt, S. D. 2014). Providing a generous supply of dry straw, along with a solid sturdy structure (a calf hutch for example) for dairy calves during colder months, will help minimize effects of cold stress. Heat lamps for newborn calves have also proven effective for many producers during low effective ambient temperatures.

ECONOMETRIC ISSUES

While the literature review conducted above is related to the first two objectives in the study, which deal with cost minimization in raising dairy calves, the literature review in this section relates to the last two objectives of the study: 3) define in detail the econometric problems that existed in Holt's study and 4) find and implement solutions to econometric problems that existed in that study.

Panel data were used for the study, meaning the data have a cross section element along with a time element (the same calves were followed throughout the study, where multiple observations were made on each of these calves through time). Panel data possess several advantages over conventional cross-sectional or time-series data sets. Panel data give a large number of data points, increase degrees of freedom, and reduce collinearity among variables. This, in turn, improves the efficiency of econometric estimates. Also, panel data allow analyses of many economic questions that could not be addressed using cross-sectional or time-series data alone. This being said, the use of panel data also has its setbacks. For example, panel data will often require addressing issues such as heteroskedasticity, which is often present in cross-sectional data, and serial correlation (autocorrelation), which is commonly found in time-series data.

Techniques Used To Analyze Panel Data

There are many different techniques used to analyze panel data. The two that seem to be used most commonly will be discussed.

The first method is called fixed effects. An econometrician should use the fixed effects model to analyze panel data when he is interested in only analyzing the impact of variables that vary over time. The fixed effects model is a method of estimating panel data equations that works by allowing each cross-sectional unit to have a different intercept. One of the advantages to using a fixed effects model is that it avoids bias due to omitted time-invariant variables (variables that do not change with time, such as gender or race). The drawbacks of using the fixed effects model are that degrees of freedom tend to be low because one degree of freedom is lost with each additional observation (cross-section). Also, any explanatory variable that does not vary across time will be perfectly collinear with the fixed effects, so it cannot be included in the model and cannot have a coefficient estimated for it.

The second method for estimating panel data is called random effects. Differing from the fixed effects model, which is based on the assumption that each cross-sectional unit has its own intercept, the random effects model is based on the assumption that the intercept for each cross-sectional unit is drawn from a distribution that is centered round a mean intercept. This means that each intercept is drawn randomly from an intercept distribution and therefore is independent of the error term for any particular observation. The random effects model is advantageous because it will have more degrees of freedom than a fixed effects model. Another advantage of using random effects is that coefficients can be estimated for time-invariant explanatory variables. The major disadvantage of using the random effects method is that the econometrician must assume that the effect of any omitted time-invariant variables is uncorrelated with the independent variables if omitted variable bias is to be avoided.

There are several possible econometric complications with the panel data set used in this study. If these issues were present in the data then the equations estimated with these data would be inaccurate, thus rendering any hypothesis testing irrelevant. The econometric issues most likely to be present include: 1) Equation Specification Error, 2) Multicollinearity, 3) Heteroskedasticity, and 4) Serial Correlation. In the four following sections, each of these issues is defined and the problems it can cause in econometric modeling are discussed. Methods for detecting if each of these issues exists are discussed and solutions to solve these issues are given. The information presented in the following four subsections was composed using as a reference the textbook *Using Econometrics: A Practical Guide Sixth Edition* by Studenmund, A.H. (2010), unless noted otherwise.

1) Equation Specification Error

A specification error occurs when the functional form used to estimate the equation does not correctly represent the relationship between each independent variable and the dependent variable.

> The most important step in applied regression analysis is the specification of the theoretical regression model. After selecting the dependent variable, the specification of a model involves choosing the following components: 1) the independent variables and how they should be measured, 2) the functional (mathematical) form of the variables, and 3) the properties of the stochastic error term. . . A mistake in any of these three elements results in a specification error. Of all the kinds of mistakes that can be made in applied regression analysis, specification error is usually the most disastrous to the validity of the estimated equation. (Studenmund, A.H., 2010)

Avoiding a specification error often means avoiding a whole range of problems in the estimated regression equation. Three of these problems are discussed in subsequent sections.

The estimation of a regression equation is determined primarily on the basis of economic theory. A good econometrician realizes that if more attention is paid to economic theory at the beginning of a project, the more likely he is to receive satisfactory results in the estimated regression equation later on. Once the dependent variable (the variable that sits alone on the left side of the equation and is the result of the interaction between one or more of the independent variables) has been chosen, the independent variables selected to be included in the equation should be chosen on the basis on economic theory. An independent variable is chosen because in theory it is a determinant of the dependent variable; the expectation is that it will explain at least part of the variation in the dependent variable. This is why independent variables are often called explanatory variables—they explain why the dependent variable is what it is. The results of the regression equation will give evidence of a relation between the independent variables and the dependent variable, but it does not prove economic causality.

An important concept in correctly specifying a regression equation is the estimation of the coefficients of the regression equation using a method called Ordinary Least Squares (OLS). OLS is a regression estimation technique that calculates the estimated coefficients so as to minimize the sum of the squared residuals. In other words, it minimizes the squared differences between the actual value of the dependent variable and the estimated values of the dependent variable produced by the regression. OLS is the most commonly used regression equation estimation method, but in some cases, a few of which will be explained in the following subsections, it may not be the best method to use.

2) Multicollinearity

Multicollinearity occurs when two or more independent variables have a linear functional relationship that is so strong that it can significantly affect the estimation of the coefficients of those variables. While perfect multicollinearity (one independent variable is a perfect linear function of one or more other independent variables) is very rare, severe multicollinearity will cause substantial problems. There are several consequences of multicollinearity:

1) Estimates will remain unbiased. Even if there is significant multicollinearity in an equation, the estimated coefficients will be centered round the true population of coefficients as long as all the Classical Assumptions are met and the equation has been correctly specified.
2) The variances and standard errors of the estimates will increase. This is the most substantial problem associated with multicollinearity. It is difficult to identify the exact effect of each multicollinear variable because they are so

significantly related to one another. When there is difficulty distinguishing the effects of one variable from the effects of another, an error in estimating the coefficients in the equation becomes much more likely than when multicollinearity is not present. The estimated coefficients come from distributions with much larger variances and larger standard errors. The larger variance, caused by multicollinearity, also increases the likelihood of obtaining an unexpected sign.

3) The computed t-scores will fall. Multicollinearity will normally decrease the estimated t-scores because of the formula for the t-statistic, which has the standard error of the estimated coefficient in the denominator. Because multicollinearity increases the standard error, the t-score for that coefficient will fall. Low t-scores in an equation is a good indication that there is high multicollinearity.

4) Estimates will become very sensitive to changes in specification. Including another explanatory variable or dropping an existing one, as well as adding or subtracting a few observations will often cause major changes in the values of the estimated coefficients when significant multicollinearity exists. If, for example, an explanatory variable that is statistically insignificant is dropped, often times the remaining variables in the equation will change drastically. Such large changes occur because OLS is forced to find small

differences between variables in order to distinguish the impact of one of the multicollinear variables to another.

5) The overall fit of the equation and the estimation of the coefficients of non-multicollinear variables will be largely unaffected. The overall fit of the equation (adjusted r-squared) will often not fall at all. If there is an explanatory variable in the equation that is not multicollinear with any of the other variables, then the estimation of its coefficient and standard error will likely be unaffected. Since multicollinearity has little effect on the overall fit of the equation, predictions and forecasting done with the equation will also be largely unaffected. One of the surest signs for multicollinearity is a high r-squared coupled with few or no statistically significant individual regression coefficients.

Although there is not a generally accepted test for multicollinearity, there are a few commonly used tests among econometricians. Two of these tests are explained here, but first it is important to recognize that some multicollinearity exists in every equation, thus these tests aim to quantify how much multicollinearity exists in the equation, not whether it exists.

One way to diagnose multicollinearity is by examining the simple correlation coefficients (*r*) between explanatory variables. If the resulting *r* is high (usually .80 or higher, though this number varies from one econometrician's opinion to the next) in absolute value, then these two explanatory variables are quite correlated and multicollinearity may be a problem. The limiting factor with the simple correlation coefficient test is that it does not test groups of independent variables for multicollinearity that could be acting together to cause multicollinearity, but instead only tests the relationship between two individual variables.

Another way of testing for multicollinearity is by using the variance inflation factor (VIF). This method detects how severe the multicollinearity is in a given equation by measuring the extent to which one of the explanatory variables can be explained by all of the other explanatory variables in the equation. Therefore each explanatory variable will have a VIF. The VIF indicates to what extent multicollinearity has increased the variance of the estimated coefficient. A high VIF, usually 5 or greater (though no hard-and-fast VIF decision rule exists) indicates that multicollinearity has caused an increase in the variance of the estimated coefficient. Just like the simple correlation coefficient test, there are limitations to the VIF test. First, like mentioned previously, there is no set VIF decision rule. Second, multicollinearity may exist in an equation that does not produce high VIF values.

There are a few things that can be done to minimize the consequences of multicollinearity. The first remedy is to do nothing. Every remedy for multicollinearity has a drawback so it is often the best decision to do nothing about it. The second option is to drop a redundant variable. This can be done because the effect on the dependent variable currently being represented by multiple independent variables, can be represented just as accurately with only one independent variable. The multicollinear variables may be combined in some fashion (e.g., added, subtracted, multiplied, or divided). Another way to attempt to limit multicollinearity is the increase the sample size. Although it is often impossible to increase the sample size, doing so will give a more accurate representation of the whole population and will normally reduce the variance of the estimated coefficients. This will minimize the impact of multicollinearity.

3) Heteroskedasticity

Heteroskedasticity occurs when the observations of the error term are drawn from a distribution that does not have a constant variance. There are two different types of heteroskedasticity: pure and impure. Pure heteroskedasticity occurs when the variance of the error term is not constant and the equation has been correctly specified. Impure heteroskedasticity occurs when the variance of the error term is not constant, but differs from pure heteroskedasticity in that it is caused by the econometrician making a specification error.

Pure heteroskedasticity occurs when the equation has been correctly specified, but there is a wide difference in the variances of the error term. On the other hand, if there is no pure heteroskedasticity in the equation then all the observations of the error term are being drawn from the same distribution; which is a distribution with a mean of zero and a constant variance. This is called homoskedasticity, and is desirable because the variance of the distribution is constant even if individual observations drawn from that sample may vary. If pure heteroskedasticity exists then the error term variance is not constant, but instead depends on which individual observation is being discussed. So instead of being constant over all observations, a heteroskedastic error term's variance can change depending on the observation.

Pure heteroskedasticity occurs most commonly in data sets that have a wide gap between the largest and smallest observed value of the dependent variable. As the disparity between the sizes of the observations of the dependent variable in a sample increases, the greater the likelihood that the error term observations associated with them will have different variances, causing heteroskedasticity. In other words, it is expected that the error term distribution for large observations will be likely to have a large variance, while the error term distribution for small observations is likely to have a small variance. By using cross-sectional data sets, it is very common to get a large range between the highest and lowest values of the variables. For example, if a study were to be conducted including the Gross Domestic Product (GDP, the total value of goods produced and services provided) of each country in the world, there would be a considerable difference between the GDP in the United States of America compared to the GDP of Honduras. Because cross-sectional data sets often include observations with a large range of sizes in the same sample, it is difficult to avoid heteroskedasticity when studying econometric topics.

Impure heteroskedasticity is caused by an equation specification error, like an omitted variable. Impure heteroskedasticity can be caused by an omitted variable because the error term must absorb the effect not represented by one of the included independent variables. If that omitted effect has a heteroskedastic element, then the error term of the incorrectly specified equation may be heteroskedastic although the error term of the true equation is not. If heteroskedasticity is present, it is crucial to know whether it is pure or impure in order to correctly remedy the problem. If, in this case, it is impure heteroskedasticity then the correct remedy is to find the omitted variable and include it in the regression equation.

There are three major consequences if the error term of an equation is heteroskedastistic:

1) Coefficient estimates will not be biased if pure heteroskedasticity is present in the error term of the equation. Since heteroskedasticity causes large positive errors to be more likely to occur, so too are large negative errors more likely to occur; this causes the coefficient errors to remain unbiased because the two tend to average each other out. This phenomena still leaves the OLS estimator unbiased. Although there is a lack of bias, there is no guarantee that the coefficient estimates will be accurate, especially considering heteroskedasticity increases the variance of the estimates, but the distribution of the estimates is still centered round the true coefficient.

Equations with impure heteroskedasticity, caused by a variable being omitted, will have possible specification bias.

2) Heteroskedasticity usually causes OLS to no longer be the minimum-variance estimator. The heteroskedastic error term causes the dependent variable to fluctuate, but the OLS estimation procedure wrongfully indicates that this fluctuation is caused by the independent variables. This causes OLS to be more likely to misestimate the true coefficient when heteroskedasticity is present.

3) Heteroskedasticity causes OLS estimates of the estimated standard errors to be biased upward, causing hypothesis testing to be unreliable. Since the estimated standard errors are a major component in the t-statistic, the biased estimated standard errors cause the t-scores to be biased also and the hypothesis testing to be unreliable. Basically, heteroskedasticity causes OLS to produce the wrong estimated standard errors and t-scores. Since pure heteroskedasticity causes hypothesis testing to become both biased and unreliable, most econometricians are not likely to consider the results of hypothesis testing meaningful when pure (or impure) heteroskedasticity is present.

Similar to other econometric issues, there is not a universally agreed upon method for detecting if heteroskedasticity exists in an equation. Although some texts have as many as eight different methods for determining if an equation has heteroskedasticity, no test can fully "prove" that heteroskedasticity exists. So the best an econometrician can hope for is to get a general indication of the likelihood that heteroskedasticity exists in an equation. Two commonly used tests to detect the likelihood of heteroskedasticity, the Park Test and the White Test, will be explained.

Since testing an equation for heteroskedasticity is quite time-consuming and because it is unnecessary to test every equation for heteroskedasticity, the econometrician should ask a few questions before running a test for heteroskedasticity. The first question is, "Does the equation have any obvious specification errors?" If, for example, the estimated equation is suspected of having an omitted variable, then the equation should be re-estimated including the omitted variable before testing for heteroskedasticity. The second question is, "Is the data in the research likely to be afflicted with heteroskedasticity?" Cross-sectional data typically are the most frequent source of heteroskedasticity, especially cross-sectional data with large variations in the size of the dependent variable. This concept goes back to the example of GDP by country mentioned earlier in this section. The last question that should be asked is, "Upon graphing the squared residuals, is there any evidence of heteroskedasticity?" If, when graphed, the squared residuals have an expanding or contracting distribution, then heteroskedasticity is likely and the equation should be tested for heteroskedasticity.

One of these tests, the Park test, uses the residuals of an equation to test if there is heteroskedasticity in the error term of that equation. There are three basic steps to the Park test:

1) Obtain the residuals of the estimated regression equation.
2) Run a double-log regression equation using the log of the squared residuals (calculated in step one) as the dependent variable. A proportionality factor, which is commonly labeled as Z, must also be selected by the econometrician. The log of this proportionality factor is used as the independent variable in the equation.
3) Test the significance of the coefficient of Z in the equation estimated in step two using a t-test. If the coefficient of Z is significantly different from zero, then this shows evidence of heteroskedastic patterns in the residuals with respect to Z. If the coefficient of Z is not significantly different from zero, then heteroskedasticity is not supported by the evidence of these residuals.

One major setback of the Park test is the identification of the proportionality factor. The selecting of the proportionality factor is left completely to the intuition of the econometrician. Most commonly, an independent variable from the originally estimated regression equation is selected as Z. It is often difficult to know which independent variable is the best choice for the proportionality factor. A good way of selecting the proportionality factor is by using an independent variable that measures the size of the observation, since heteroskedasticity is highly related to the size of the observations.

Another test that checks for heteroskedasticity is the White test. This test differs from the Park test in that it is not necessary to identify the proportionality factor. For this reason the White test seems to be rapidly gaining support as the most appropriate test to use for the detection of heteroskedasticity. Thus, if an econometrician is having difficulty with the Park test because he does not know which independent variable to choose as the proportionality factor, instead of running a series of Park tests, it is advisable that the White test be conducted.

The White test, similar to the Park test, uses the squared residuals of the originally estimated regression equation as the dependent variable. With the White test, though, the right-hand side of the secondary equation includes all of the original independent variables, all of the original independent variables squared, and the cross products of all the original independent variables with each other. More specifically the three steps of the White test are:

1) Calculate the residuals of the originally estimated regression equation.
2) Use the residuals squared as the dependent variable in a second equation. Include as independent variables all of the independent variables from the original equation, all of the original independent variables squared, and the cross products of all the original independent variables with each other.

3) Test the overall significance of the estimated regression equation from step two using the chi-square test. The test statistic used here is the sample size multiplied by the unadjusted r-squared from the equation estimated in step two. If the test statistic is larger than the critical chi-square value found on the chi-square distribution table, then the null hypothesis must be rejected and the conclusion is that heteroskedasticity is likely. If the test statistic is smaller than the chi-square value found on the table, then the null hypothesis of homoskedasticity cannot be rejected and it can be concluded that heteroskedasticity is unlikely.

One limitation of the White test is that sometimes the second equation cannot be estimated because it has a small number or even negative degrees of freedom. This can happen when the original equation has a small sample size or the original equation has so many independent variables that the second estimated equation ends up having more independent variables (because of the squared and cross-product independent variables) than observations.

There are a few commonly used remedies for heteroskedasticity. The most regularly used remedy is heteroskedasticity-corrected standard errors, which uses the original OLS estimates of the slope coefficients while adjusting the estimation of the standard errors of the estimated coefficients for heteroskedasticity. This is a logical remedy, since heteroskedasticity causes problems with the standard errors of the estimated coefficients but not with the estimated coefficients themselves. Thus, it makes sense to improve the estimation of the standard errors of the estimated coefficients in a way that does not alter the estimations of the coefficients themselves.

Another approach to the elimination of heteroskedasticity from an equation is to go back to the basic underlying theory of the equation and redefine the variables in a way that avoids heteroskedasticity. Although redefining the variables in an equation may be difficult and discouraging because it means changing work that has already been done, it is sometimes the best way to remedy heteroskedasticity. The econometrician should exercise caution when redefining variables because it is a functional form specification change that can radically change the equation; although sometimes the only redefinition that is needed to rid the equation of heteroskedasticity is to switch from a linear functional form to a double-log functional form. There is naturally less variation in the double-log form than in the linear form, so it's less likely to suffer from heteroskedasticity. Unfortunately, no zero or negative values can be used in the regression due to the log form of the variables. Also, the linear functional form is often chosen by default, the researcher not knowing which functional form would be the best fit for the data. Upon further investigation, the researcher may find that the double-log form is a better fit for the data. In other situations, it may be necessary to totally rethink the theoretical theory behind the study and make more extreme changes to the regression equation.

Yet another strategy of ridding an equation of heteroskedasticity is by estimating the equation with Newey-West Standard Errors. This method will be discussed in greater detail in the next section, since the Newey-West approach is also a method used to rid an equation of serial correlation.

4) Serial Correlation

Serial correlation exists when the value of the error term from one time period depends in some systematic way on the value of the error term in other time periods. Just like with heteroskedasticity, serial correlation can either be pure or impure. In addition to this, serial correlation can also take on several different forms. The most commonly assumed form of serial correlation is first-order serial correlation, where the current value of the error term is a function of the previous value of the error term. Other possible forms of serial correlation are annual, quarterly, or seasonal serial correlation, for example. Second-order serial correlation is yet another form of serial correlation, i.e., the error term in the equation is a function of more than one of the previous observation of the error term.

There are two basic ways that serial correlation is caused in an equation. The first is when the equation has been correctly specified and the current value of the error term is correlated with the error term from other time periods. This is pure serial correlation. In this case the serial correlation is caused by the underlying distribution of the error term of the true specification of the equation. Therefore, the econometrician cannot alter the true specification of the equation, although there are remedies for the problem. The second way serial correlation is caused is by making a specification error, such as having an omitted variable or an incorrect functional form. This is impure serial correlation. This is because the error term for an incorrectly specified equation includes the effect of any omitted variables. Since this second cause of serial correlation can be controlled by the econometrician, it can often be corrected by simply re-estimating the equation in the correct function form.

There are a few major consequences of serial correlation:

1) Pure serial correlation does not cause bias in the coefficient estimates. The distribution of the estimated coefficients will still be centered on the true coefficient. However, if the serial correlation is impure, bias could be introduced by a specification error. The OLS estimates of the coefficients of a serially correlated equation will not necessarily be close to the true coefficient values. By saying that pure serial correlation does not cause bias in the coefficient estimates means that the distribution of the coefficient estimates will still be centered on the true coefficient. Also, the standard errors of these estimates will usually be increased by serial correlation, increasing the probability that the coefficient estimates will differ significantly from the true coefficient value.

2) Serial correlation causes Ordinary Least Squares (OLS) to no longer be the minimum variance estimator. When the error term is serially correlated, it causes the dependent variable to fluctuate in such a way that the OLS estimation procedure wrongfully attributes this fluctuation to the explanatory variables. This being the case, OLS is more likely to misestimate the true coefficient when the equation suffers from serial correlation.
3) Serial correlation causes the OLS estimates of the standard errors of the estimated coefficients to be biased, causing unreliable hypothesis testing. Because the standard errors play a large part in the calculation of the t-statistic, these biased estimates of the standard errors cause biased t-scores and unreliable hypothesis testing in general. Basically, serial correlation causes OLS to produce incorrect estimates of the standard errors which results in incorrect t-scores. For this reason, most econometricians are unlikely to consider hypothesis tests that were conducted with an equation suffering from serial correlation as valid.

The most widely used method for detecting serial correlation is the Durbin-Watson d-test. The Durbin-Watson d-statistic is used to determine if there is first-order serial correlation in the error term of an equation by examining the residuals of the estimation of that equation. The Durbin-Watson d-statistic can only be used when the assumptions underlying its origin are met. These assumptions are: 1) the regression model has an intercept term, 2) the serial correlation in the equation is first-order serial correlation, and 3) the regression equation does not include a lagged dependent variable as an independent variable. Most statistical software will easily calculate the d-statistic, but an econometrician must interpret the results.

The Durbin-Watson test is unusual in that there is not only acceptance and rejection regions, referring to the decision rule when hypothesis testing, but a third region, called the inconclusive region. Besides this fact, the Durbin-Watson d-test is very similar to the t-test. The three steps of conducting the Durbin-Watson d-test are:

1) Obtain the OLS residuals from the equation and use them to calculate the d-statistic (this is normally done by the statistical computer program).
2) Using the sample size and the number of explanatory variables in the equation, consult the critical values of the Durbin-Watson test statistics chart to determine the upper critical d-value and the lower critical d-value. The author of the table should also include instructions on how to use it.
3) Use the critical values found in step two to set up a hypothesis test of the Durbin-Watson d-statistic. The null hypothesis is that there is no positive serial correlation, while the alternative hypothesis is that there is positive serial correlation. The decision rule is if the Durbin-Watson d-statistic is less than the lower critical d-value then reject the null hypothesis, meaning that there is positive serial correlation. If the Durbin-Watson d-statistic is greater

than the upper critical d-value then do not reject the null hypothesis, meaning there is no serial correlation. If the Durbin-Watson d-statistic falls above the lower critical d-value and below the upper critical d-value then the decision rule is inconclusive.

If the Durbin-Watson d-statistic detects serial correlation in the residuals of the equation, the best place to start in correcting the problem is to look carefully at the specification of the equation for possible errors that may be causing impure serial correlation, such as an omitted variable. Impure serial correlation is often caused by a specification error, so only after the specification of the equation has been reviewed should the possibility for an adjustment for pure serial correlation be considered.

In the manual *EViews 7 User's Guide II*, it explains that if there is no serial correlation, the Durbin-Watson statistic will be around 2. The Durbin-Watson statistic will fall below 2 if there is positive serial correlation (in the worst case, it will be near zero). If there is negative correlation, the statistic will lie somewhere between 2 and 4. Positive serial correlation is the most commonly observed form. As a rule of thumb, with 50 or more observations and only a few independent variables, a Durbin-Watson statistic below about 1.5 is a strong indication of positive first order serial correlation (Quantitative Micro Software, LLC., 2009). If it is concluded that there is pure serial correlation, then the econometrician should consider applying Generalized Least Squares (GLS) or Newey-West standard errors.

Generalized Least Squares is one method of ridding an equation of first-order serial correlation. GLS also restores the minimum variance property to the equation when making an estimation. GLS will take an equation that does not meet the Classical Assumptions (serial correlation for example) and transforms it into an equation that does meet the Classical Assumptions. The GLS model can easily be estimated using most statistical computer programs. There are some key points worth noting about the equation estimated by GLS: the error term will not be serially correlated, the coefficients estimated with GLS will have the same meaning as those estimated with OLS, but the adjusted r-squared from the GLS estimate is not directly comparable to the adjusted r-squared from the OLS estimate because the dependent variable will have changed.

The Newey-West Standard Errors approach is another method used to remedy pure serial correlation. Newey-West Standard Errors are standard errors of the estimated coefficients that take account of serial correlation without changing the estimated coefficients themselves. This is a logical method, since serial correlation affects the standard errors and not the estimated coefficients. The Newey-West Standard Errors are calculated specifically to avoid the consequences of pure first-order serial correlation. The Newey-West Standard Errors can be used for t-tests and other hypothesis testing without errors of inference caused by serial correlation. When comparing the estimated equation using Newey-West Standard Errors and the equation containing serial correlation there are a couple observations that can be made: the estimated coefficients are identical in each estimated equation (Newey-West Standard Errors do not change the estimated coefficients that were calculated when using OLS), while the Newey-West Standard Errors are different from the OLS standard errors, changing the t-scores as well.

CHAPTER III

DATA & ANALYSIS

As mentioned above panel data were used for the study, meaning the data have a cross section element along with a time element (the same calves were followed throughout the study, where multiple observations were made on each of these calves through time). The heifer calves used in this study were housed at the George B. Caine Dairy Teaching and Research Center at Utah State University. Normal husbandry practices for newborn calves were followed such as the feeding of colostrum within 24 hours of birth and iodine treatment of the navel. The Holstein heifer calves used in the study were housed in individual hutches with a small exercise area in front, and became part of the study within the first 48 hours of birth. The study spanned from April 2011 to February 2012, and the calves remained on the study until they were weaned (Holt, S. D., 2014).

The calves were given milk twice daily at 0500 and 1700 hours. The norm at the Caine Dairy Farm is to feed calves 4 quarts of whole milk per day from June to the end of September and 6 quarts of whole milk per day during the remainder of the year; although a small trial was run as a subset of the main trial from September 27, 2011 to December 21, 2011, where calves were alternately selected as they were born to receive either 4 quarts of milk per day or 6 quarts of milk per day. Free choice calf starter grain was offered to each calf starting at one week of age, and each calf was free to eat up to a maximum of 7 pounds per day. In order to measure the amount of starter intake, grain refusal was gathered and documented during each milk feeding. Once per week the calves were weighed and their hip and wither heights were measured. Calf health scores were given at each evening milk feeding, to identify overall calf health. The criteria used to determine health scores was developed at the University of Wisconsin and is named the University of Wisconsin School of Veterinary Medicine University Scoring Criteria.

There were multiple independent variables used in the study, although several of them were dropped from the final multivariate equation because they were insignificant or did not belong in the equation according to economic theory. Calf weight in pounds was used as the dependent variable. The independent variables, and their definitions are listed below in *TABLE 1*:

Table 1 Independent Variables Defined

Independent Variable	**Definition**
Days since birth	The number of days since the calf was born
Hip	Measurement of calf hip height in inches (measured from the top of the hip bones to the bottom of the calf's back hooves)
Wither	Measurement of calf wither height in inches (measured from top of the shoulder blades to the bottom of the calf's front hooves)
Intake AM	Amount of starter grain consumed from 2200 hours to 0959 hours. Grain refusal was collected and recorded during each feeding to monitor individual grain intake.

Intake PM	Amount of starter grain consumed from 1000 hours to 2159 hours. Grain refusal was collected and recorded during each feeding to monitor individual grain intake.
Milk6	A dummy variable that took a value of one if a calf was fed 6 quarts of milk per feeding or a value of zero if 4 quarts of milk were given per feeding
Relative Humidity AM	Average percent humidity from 2200 hours to 0959 hours
Relative Humidity PM	Average percent humidity from 1000 hours to 2159 hours
Score	A whole number score was given to each calf daily, representing overall health. Scores ranged from 0-3 where 0 represents a completely healthy calf and 3 represents a calf with extreme health problems. Please see: http://www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_health_scoring_chart.pdf
Temperature AM	Average temperature in degrees Celsius from 2200 hours to 0959 hours
Temperature PM	Average temperature in degrees Celsius from 1000 hours to 2159 hours
Precipitation AM	Amount of precipitation in millimeters from 2200 hours to 0959 hours
Precipitation PM	Amount of precipitation in millimeters from 1000 hours to 2159 hours
Wind speed AM	Average wind speed in meters per second from 2200 hours to 0959 hours
Wind speed PM	Average wind speed in meters per second from 1000 hours to 2159 hours
Barometer AM	Average barometric pressure in millimeters of mercury (mmHg) from 2200 hours to 0959 hours
Barometer PM	Average barometric pressure in millimeters of mercury (mmHg) from 1000 hours to 2159 hours
Winter	A dummy variable representing the months December, January, and February
Spring	A dummy variable representing the months March, April, and May
Summer	A dummy variable representing the months June, July, and August
Fall	A dummy variable representing the months September, October, and November

All weather related information was collected hourly and summarized into two periods 2200 to 0959 h (AM period) and 1000 to 2159 h (PM period) in order to analyze effects of day and night separately. These data were collected from a weather station maintained by the USU Climate Center located 0.81 miles (1.3 km) north of where the calves were housed in individual hutches. All calf related data were collected and recorded by Holt, S D. (2014).

The panel data were arranged in long form such that all observations for the same calf were listed consecutively through the days that the calf remained on the study. Each calf remained on the study until it was weaned. Some calves were already born and lived in the hutches for several days or even weeks when the study was initiated. Likewise, some calves included in the study were still in the hutches when the study ended. Because of the way the data are organized, this does not have any effect on the statistical analysis. Statistical analyses were performed using the computer programs, EViews 8 and StataMP 13.

CHAPTER IV

RESULTS

In order to determine the effect the independent variables in the study had on the dependent variable calf weight, a regression equation was estimated. An estimated regression equation is not only useful for showing the effect that independent variables have on the dependent variable, but can also be used to predict future outcomes.

SPECIFICATION ERROR AVOIDED

Avoiding a specification error often means avoiding a whole range of problems in the estimated regression equation, therefore it was important to find the functional form that best fit the data in the study. This was done by estimating the equation using the classical linear regression model, Ordinary Least Squares (OLS) first. Overall, the data followed a linear trend, so it was hypothesized that OLS would provide the best fit for the data. After attempting to estimate an equation using logged variables, which was impossible since the data had zero and negative values, and considering other functional forms it was concluded that using a linear OLS model was the best fit for the data.

MULTICOLLINEARITY TESTING AND SOLUTIONS

Before an equation was estimated, the data were first tested for multicollinearity using the statistical analysis programs EViews 8 and StataMP 13. Although any given equation will contain some multicollinearity, a large amount in the data being worked can cause several problems. For example, the variances and standard errors of the estimates will increase and the computed t-scores will fall. Because of the nature of the data used for this study, it was suspected that a large amount of multicollinearity could be a problem in the data set.

In order to test the data for multicollinearity two methods were used. The first method was to examine the simple correlation coefficients (*r*) between explanatory variables, and the second method was to use the variance inflation factor (VIF) test. Since there were several independent variables whose values were measured in morning and evening time blocks, it was assumed that if multicollinearity was an issue, it would present itself most strongly amongst these variables. Thus, the simple correlation coefficients test was conducted in EViews 8 on these ten variables. The results of the test are shown in *TABLE 2*. The cells where problems might exist have been highlighted in yellow. Since a diagonal line placed from the top left corner of the table to the bottom right corner of the table creates a mirror image of the simple correlation coefficient values, only one side of the table is displayed.

Table 2 Simple Correlation Coefficients

Simple Correlation Coefficients										
	Intake_AM	Intake_PM	Precip_AM	Precip_PM	Rh_AM	Rh_PM	Temp_AM	Temp_PM	Wind_AM	Wind_PM
Intake_AM	1.000									
Intake_PM	0.915	1.000								
Precip_AM	-0.013	-0.011	1.000							
Precip_PM	0.006	-0.010	0.254	1.000						
Rh_AM	0.117	0.098	0.224	0.181	1.000					
Rh_PM	0.130	0.105	0.205	0.393	0.732	1.000				
Temp_AM	-0.211	-0.169	0.067	-0.030	-0.629	-0.615	1.000			
Temp_PM	-0.208	-0.168	-0.026	-0.166	-0.628	-0.762	0.942	1.000		
Wind_AM	0.033	0.028	0.070	0.070	-0.422	-0.086	0.113	-0.028	1.000	
Wind_PM	0.018	0.015	0.061	0.085	-0.279	-0.142	0.096	-0.001	0.537	1.000

The *r* value for the variables intake_am and intake_pm is 0.915, meaning that these variables are highly correlated. If the resulting *r* is high (usually .80 or higher in absolute value) then these two explanatory variables are quite correlated and multicollinearity may be a problem. In other words, the closer the cross-section value (*r*) is to one, the stronger the linear functional relationship is between the two variables. According to the simple correlation coefficients test the following independent variables are highly correlated: tempc_am and tempc_pm (0.942), and intake_am and intake_pm (0.915). In order to get further verification that multicollinearity is present in the data, the variance inflation factor (VIF) test was also used.

The VIF test detects how severe the multicollinearity is in a given equation by measuring the extent to which one of the explanatory variables can be explained by all of the other explanatory variables in the equation. The VIF indicates to what extent multicollinearity has increased the variance of the estimated coefficient. A high VIF, usually 5 or greater but no hard-and-fast VIF decision rule exists, indicates that multicollinearity has caused an increase in the variance of the estimated coefficient to the point that the t-score of that estimated coefficient decreases significantly. The VIF of each of the four variables mentioned in the previous paragraph was estimated. The formula for the VIF of an independent variable is:

$$VIF = \frac{1}{(1-R^2)} \tag{11}$$

The R^2 in the formula is the unadjusted R^2 resulting from running an auxiliary equation where the independent variable in question is used as the dependent variable and the remaining independent variables are used as the independent variables in the equation. The results of the VIF test of the four independent variables are as follows:

$$VIF\ of\ tempc\_am = \frac{1}{(1-.954)} = 21.74 \tag{12}$$

$$VIF\ of\ tempc\_pm = \frac{1}{(1-.965)} = 28.57 \tag{13}$$

$$VIF\ of\ intake\_am = \frac{1}{(1-.861)} = 7.19 \tag{14}$$

$$VIF\ of\ intake\_pm = \frac{1}{(1-.857)} = 6.99 \quad (15)$$

The results of the VIF test and the simple correlation coefficient test both show that high amounts of multicollinearity are present in the equation. In order to minimize the consequences of multicollinearity in the equation, the optimal solution would be to increase the sample size, thus giving a more accurate representation of the whole population. This will normally reduce the variance of the estimated coefficients. Since this solution was impossible, the variable tempc_pm was dropped from the equation. This was done because the effect on the dependent variable that was being represented by the variable tempc_pm seemed to be represented just as accurately by the remaining independent variables included in the equation, especially by tempc_am. Since the temperature measured in the pm hours was measured immediately after the temperature in the am hours each day, they are highly correlated.

The variable tempc_pm had the highest VIF value out of the four variables identified. Also, after tempc_pm was dropped from the equation, the p-values for the variables tempc_am and rh_pm improved from 0.0716 to 0.0006 and from 0.2825 to 0.1151 respectively, further verifying that multicollinearity exists between tempc_pm and other independent variables. Furthermore the VIF of tempc_am was then calculated after the variable tempc_pm had been dropped from the equation:

$$VIF\ of\ tempc\_am = \frac{1}{(1-.756)} = 4.10 \quad (16)$$

Now, with a VIF value of 4.10 tempc_am the likelihood of severe multicollinearity existing between tempc_am and the remaining independent variables is decreased significantly. The VIF values of the variables intake_am and intake_pm are also significantly greater than 5 and the simple correlation coefficient between these two variables is also quite high.

According to economic theory, calf starter intake during all hours is relevant and important to a calf's growth, thus it was crucial that these two variables were left in the equation. In order to correct for multicollinearity between intake_am and intake_pm, a new variable was created by adding intake during the am and pm hours together. This eliminated the multicollinearity between intake_am and intake_pm, while still capturing the effect that each of these independent variables had on the dependent variable calf weight. Having minimized the amount of multicollinearity amongst the variables, an equation using the random effects model was estimated. Equation 17 shows the variables that were included in the estimation (refer to *Table 1* for definitions of the independent variables included in the equation).

$$Weight = \beta_0 + \beta_1 Win + \beta_2 Sum + \beta_3 Spr + \beta_4 hip + \beta_5 TotalIntake + \beta_6 score + \beta_7 RHAM + \beta_8 RHPM + \beta_9 PrecipitationmmAM + \beta_{10} PrecipitationmmPM + \beta_{11} dayssincebirth + \beta_{12} TempCAM + \beta_{13} WindmsAM + \beta_{14} WindmsPM \quad (17)$$

HETEROSKEDASTICITY AND SERIAL CORRELATION TESTING AND SOLUTIONS

The random effects model was used because it allows for more degrees of freedom than a fixed effects model. A fixed effects model equation was also estimated however, but several of the variables were insignificant in the estimation, thus the random effects model was used for this study. This equation, *Figure 2*, was estimated in StataMp 13.

The data were then tested for heteroskedasticity, and, as expected there were high amounts of heteroskedasticity in the data. The White test was conducted on the data to detect this heteroskedasticity. The results of the test are shown in *Figure 3*.

With a large chi-squared value (1555.03) and a p-value of 0.00, heteroskedasticity was undoubtedly a problem in the data. The skewness in *Figure 3* is a measurement of the lack of symmetry in the data. Since the skewness value is positive, the distribution is heavier on the right side of its distribution peak or center point. Kurtosis measures whether the data are peaked or flat relative to a normal distribution. Since the kurtosis value is high (above 3) the data have a distinct peak near the mean, will then decline rapidly with a heavy tail to the right of the mean (NIST/SEMATECH, 2012).

Figure 2 Random Effects Model

Random-effects GLS regression		Number of obs	= 6061
Group variable: calfID		Number of groups	= 98
R-sq: within	= 0.9585	Obs per group: min	= 1
between	= 0.9422	avg	= 61.8
overall	= 0.9378	max	= 117
		Wald chi2(14)	= 137822.02
corr(u_i, X)	= 0 (assumed)	Prob > chi2	= 0.0000

weight	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Win	8.59582	.6322018	13.60	0.000	7.356727	9.834913
Sum	12.27884	.5808195	21.14	0.000	11.14046	13.41723
Spr	3.778101	.8792287	4.30	0.000	2.054844	5.501357
hip	8.412547	.2123993	39.61	0.000	7.996252	8.828842
TotalIntake	.16255	.0052118	31.19	0.000	.152335	.1727649
score	-.1114415	.1762791	-0.63	0.527	-.4569422	.2340591
RHAM	-.0512917	.0190732	-2.69	0.007	-.0886745	-.0139089
RHPM	.0221702	.0138903	1.60	0.110	-.0050543	.0493947
PrecipitationmmAM	2.775631	.6402187	4.34	0.000	1.520825	4.030436
PrecipitationmmPM	-1.825479	.7140248	-2.56	0.011	-3.224942	-.4260163
dayssincebirth	.7730226	.0224893	34.37	0.000	.7289443	.8171009
TempCAM	.1104926	.0326896	3.38	0.001	.0464222	.1745631
WindmsAM	-.9447543	.2065726	-4.57	0.000	-1.349629	-.5398794
WindmsPM	.008151	.1572911	0.05	0.959	-.3001339	.3164358
_cons	-197.764	6.981476	-28.33	0.000	-211.4475	-184.0806
sigma_u	6.2835515					
sigma_e	9.7607216					
rho	.29299919	(fraction of variance due to u_i)				

Heteroskedasticity, and the problem of serial correlation, was minimized by estimating the equation using a Newey-West standard errors model. Although estimating an equation using Newey-West standard errors is typically done to eliminate the effects of serial correlation, it will also eliminate heteroskedasticity from an equation.

Figure 3 White Test

White's test for Ho: homoskedasticity
against Ha: unrestricted heteroskedasticity

chi2(113) = 1555.03
Prob > chi2 = 0.0000

Cameron & Trivedi's decomposition of IM-test

Source	chi2	df	p
Heteroskedasticity	1555.03	113	0.0000
Skewness	276.35	14	0.0000
Kurtosis	37.95	1	0.0000
Total	1869.33	128	0.0000

In order to test for serial correlation, the Durbin-Watson d-statistic was used. After determining the sample size and the number of explanatory variables in the equation, the Durbin-Watson test statistics chart was used to determine the upper critical d value (1.895) and the lower critical d value (1.225). When using the Durbin-Watson d-statistic, the null hypothesis is that there is no positive serial correlation, while the alternative hypothesis is that there is positive serial correlation. The decision rule is if the Durbin-Watson d-statistic is less than the lower critical d-value then reject the null hypothesis meaning that there is positive serial correlation. If the Durbin-Watson d-statistic is greater than the upper critical d-value then do not reject the null hypothesis meaning that there is no positive or negative serial correlation. If the Durbin-Watson d-statistic falls above the lower critical d-value and below the upper critical d-value then the decision rule is inconclusive. In this study, the value for the Durbin-Watson d-statistic in the model was 0.1235. Thus there was positive serial correlation in the equation.

To correct for serial correlation a Newey-West standard errors model equation was estimated. Newey-West standard errors were used because they are standard errors of the estimated coefficients that take account of serial correlation without changing the estimated coefficients themselves. This is a logical method considering serial correlation affects the standard errors and not the estimated coefficients. The Newey-West standard errors can be used for t-tests and other hypothesis testing without errors of inference caused by serial correlation. Thus the estimated coefficients do not change between OLS and the Newey-West approach, but the Newey-West standard errors are different from the OLS standard errors, which changed the t-scores as well. Also, the Newey-West standard errors correct for heteroskedasticity. The results of the Newey-West standard errors equation are shown in *Figure 4*.

Figure 4 Newey-West Standard Errors Equation First Attempt

```
Regression with Newey-West standard errors          Number of obs  =      6061
maximum lag: 7                                      F( 14,   6046)  =   1082.38
                                                    Prob > F        =    0.0000
```

weight	Coef.	Newey-West Std. Err.	t	P>|t|	[95% Conf.	Interval]
Win	8.706253	1.402038	6.21	0.000	5.957759	11.45475
Sum	13.17346	1.427797	9.23	0.000	10.37447	15.97245
Spr	8.872519	1.223497	7.25	0.000	6.474028	11.27101
hip	10.00259	.4489329	22.28	0.000	9.122525	10.88266
TotalIntake	.236785	.0133951	17.68	0.000	.2105258	.2630442
score	-.4681274	.3083017	-1.52	0.129	-1.072509	.1362539
RHAM	-.069361	.0259815	-2.67	0.008	-.1202939	-.0184281
RHPM	.0568959	.0234554	2.43	0.015	.010915	.1028768
PrecipitationmmAM	2.350285	.8838967	2.66	0.008	.6175326	4.083038
PrecipitationmmPM	-1.653263	.9299244	-1.78	0.075	-3.476246	.1697202
dayssincebirth	.4671591	.0475987	9.81	0.000	.3738486	.5604696
TempCAM	-.1990974	.076247	-2.61	0.009	-.3485687	-.0496261
WindmsAM	-.8493413	.2842261	-2.99	0.003	-1.406526	-.2921568
WindmsPM	.2886318	.2330634	1.24	0.216	-.1682555	.7455192
_cons	-247.1429	14.74841	-16.76	0.000	-276.055	-218.2308

Three of the independent variables in *Figure 4*, score, precipitation PM, and wind speed PM, were not significantly greater than zero (each of these independent variables' lower confidence interval value was negative, while the upper confidence level interval was positive). Each of their p-values were too high to be considered significant at the 95% confidence interval and each of their t-scores were below 2 in absolute value. Considering the insignificance of these three variables, another equation was estimated eliminating score, precipitation PM, and wind speed PM. The results are shown in *Figure 5*.

Figure 5 Newey-West Standard Errors Equation Second Attempt

Regression with Newey-West standard errors | Number of obs = 6626
maximum lag: 7 | F(11, 6614) = 1414.08
Prob > F = 0.0000

weight	Coef.	Newey-West Std. Err.	t	P>|t|	[95% Conf.	Interval]
Win	9.392349	1.379092	6.81	0.000	6.688883	12.09582
Sum	12.86406	1.36585	9.42	0.000	10.18656	15.54157
Spr	9.084654	1.19463	7.60	0.000	6.742794	11.42651
hip	9.816022	.4423927	22.19	0.000	8.948789	10.68325
TotalIntake	.2362152	.0130377	18.12	0.000	.210657	.2617734
RHAM	-.051459	.0248035	-2.07	0.038	-.1000819	-.0028362
RHPM	.039552	.0202663	1.95	0.051	-.0001765	.0792805
PrecipitationmmAM	2.026131	.8889082	2.28	0.023	.2835845	3.768678
dayssincebirth	.4877056	.0476632	10.23	0.000	.3942703	.5811409
TempCAM	-.1879596	.0738471	-2.55	0.011	-.3327238	-.0431954
WindmsAM	-.6817341	.3079935	-2.21	0.027	-1.285501	-.0779674
_cons	-241.9639	14.48746	-16.70	0.000	-270.364	-213.5638

Although the calf health scoring was determined using the University of Wisconsin's detailed scoring criteria, the insignificance of the "score" variable was arrived at subjectively because it was being done by one or more individuals. Thus, the insignificance of this variable could partly be attributed to human error. Two other possible causes of the insignificance of the variable score are that few calves in the study got sick or the score variable is simply a poor indicator of calf weight gain. The independent variables precipitation PM and wind speed PM, were likely insignificant because their effect upon calf weight was represented well enough in the variables precipitation AM and wind speed AM, respectively.

INTERPRETATION OF FINAL EQUATION

There were several key observations that were made with this equation. A 95% confidence interval was used for each of the variables. A t-score with an absolute value of 2 or greater or a p-value of 0.05 or less was considered acceptable.

Possibly one of the most significant observations is that all three of the coefficient values for winter, summer, and spring are positive, meaning the calves that were raised during these three seasons would be expected to weigh more than those raised in the fall months. This was likely because of the high fluctuation in temperature during the fall months (very cool nights and hot days). The TNZ of a calf one month old or less is between 50°F and 78°F. Average AM temperatures during the fall months were consistently below the TNZ of a one month old calf, while average PM temperatures did not exceed 78°F, but did often reach the high 60s and low 70s. In these conditions, the calves were spending energy on maintaining body temperature instead of putting that energy toward growth.

Recent studies have also shown that maternal heat stress during late gestation negatively affects the growth and metabolism of offspring during pre- and postpartum periods. Maternal heat stress also affects the immune function of the offspring. After the feeding of the same amount of colostrum from their respective dams, calves from heat-stressed cows were not able to absorb as much of the nutrients from the colostrum compared to the calves from cooled cows (Tao, S. and Dahl, G. E. 2013). This is another possible cause of the lower growth rate of the calves in the study that were raised during the fall months, since their mothers were in the final stage of gestation during the summer months.

Holding all other variables constant, dairy calves raised during the summer months were expected to weigh 12.86 pounds more than calves raised during the fall months. Calves raised during the spring months were expected to weigh 9.08 pounds more than those raised in the fall months, while those raised during the winter months were expected to weigh 9.39 pounds more than those raised during the fall months, holding all other variables constant.

Hip height had a significant impact on calf weight, which was expected. With a coefficient value of 9.82, each additional inch in height that was measured on a calf's hip, it was expected that its weight would increase by 9.82 pounds, holding all other variables in the equation constant.

Starter grain intake was another variable that had an impact on calf weight gain. In order to simplify the process of feeding the dairy calves starter grain, a scoop was used to measure the amount of feed offered to them. Uneaten starter grain was collected and measured every 12 hours (at AM and PM feedings). The units used to measure starter grain were such that one pound of starter grain was equal to 24 units of starter grain. Since the total allowance per calf per day (24 hour period) was 7 pounds, the total number of units offered to each calf per day was 168. Starting at one week of age, each calf was given 84 units of starter grain at the beginning of the AM hours and

84 units at the beginning of the PM hours for a total of 168 units or 7 pounds each day. The independent variable total intake was representative of the amount consumed during a 24 hour period. For each additional unit of starter grain (0.042 lbs.) consumed in a 24 hour period by a calf, there was an expected increase of 0.24 pounds in that calf's weight. The pounds of starter grain per unit of starter grain were calculated as follows:

$$lbs. of\ starter\ grain = \frac{1}{168} \times 7 \tag{17}$$

To explain further, if a calf ate all 168 units (7 pounds) of calf starter in a 24 hour period, it was expected that this calf would weigh 40.32 pounds more than a calf who ate zero pounds of calf starter, holding all other variables constant. Although the coefficient for total intake was a low number, when compared to the majority of the other variables' coefficients, it had a very significant impact on calf weight.

The relative humidity in the AM hours had a negative impact on calf weight in the study. This means that for every one percent increase in relative humidity in the AM hours, it was expected that the weight of the calf would decrease by 0.05 pounds, holding all other variables in the equation constant. Although the t-score and p-value of relative humidity during the AM hours were within the range for an independent variable to be considered significant, they were only barely so. Relative humidity AM seemed to have little effect on dairy calf weight when compared to other variables in the equation.

The variable relative humidity PM was left in the equation because the t-score and p-value were both only slightly outside of the range that was considered acceptable for a variable. Calf weight and relative humidity during the PM hours were positively correlated. With a one percent increase in relative humidity during the PM hours, it was expected that there would be a 0.04 increase in calf weight. Essentially, the variables relative humidity AM and relative humidity PM offset each other, meaning that the overall impact that relative humidity had on the weight gain of the calves in the study was negligible.

AM precipitation had a positive impact on calf weight. For every additional millimeter of precipitation recorded from 2200 hours to 0959 hours, calf weight was expected to increase by 2.03 pounds, holding all other variables constant. AM precipitation had a positive impact on calf weight during cold months because cloud cover at night causes temperatures to remain warmer. AM precipitation during the hot months positively impacted calf weight by cooling down the ambient temperature.

The number of days since birth had an obvious positive impact on calf weight. For each additional day after birth, a calf was expected to weigh an additional 0.49 pounds, holding all other variables constant.

For every one unit increase in average degrees Celsius during the AM hours in a one week period, calf weight was expected to decrease by 0.19 pounds. While the t-score and p-value for temperature AM were not very strong, high temperatures seemed to negatively affect the dairy calves in the study. Cattle seem to be more sensitive to high temperatures that they are to low temperatures, which may explain the negative impact that increases in AM temperature had on calf weight.

AM winds also negatively impacted calf weight. For each unit increase in average wind speed in meters per second from 2200 hours to 0959 hours, calf weight was expected to decrease by 0.68 pounds. The t-score and p-value for wind speed AM were both very weak. This considered, the values were within the acceptable range meaning that AM winds did have an impact on calf weight.

CHAPTER V

COST ANALYSIS

One of the objectives of this study was to develop a model which minimizes cost of starter feed (which is a variable controlled by the dairy producer). While there are a few variables that could be controlled to a certain point by the dairy producer, for instance, the time of year the dairy producer breeds his heifers and cows could control for the season dummy variable for example, the variable in the study that could most feasibly be controlled by producers was the calf starter intake level.

Calf starter intake was arguably one of the variables with the most impact on calf weight in the study. If a calf ate all 168 units (7 pounds) of calf starter per day, it was expected that this calf would weigh 40.32 pounds more than a calf who ate zero pounds of calf starter, holding all other variables constant. This is a considerably larger impact on calf weight than the variable summer, for instance, which is the variable with the highest coefficient value (12.86). Even if a calf were to eat 3.5 pounds of calf starter in a 24 hour period, that calf would be expected to weigh 20.16 pounds more than a calf who at zero pounds of calf starter during the same 24 hours. However, the younger a calf is, the less effect calf starter intake is expected to have on its weight since a younger calf will likely eat less than one that is older. On average, calves in the study did not start eating 3.5 pounds of calf starter each day until they reached the age of 7 to 8 weeks.

The equation showing the variables that were included in the final analysis is shown in equation 18. The independent variables are defined in *Table 1*:

$$Weight = \beta_0 + 9.39Win + 12.86Sum + 9.08Spr + 9.82hip + 0.24TotalIntake - 0.05RHAM + 0.04RHPM + 2.03PrecipitationmmAM + 0.49dayssincebirth - 0.19TempCAM - 0.68WindmsAM \quad (18)$$

The marginal physical product (MPP) shows how much calf weight changed as the amount of starter intake changed. The MPP here shows that for each additional unit of starter grain intake (0.042 lbs.), calf weight was expected to increase by 0.24 lbs., holding all other variables constant. Since, physiologically a calf can be weaned when it begins consuming 2 pounds of starter grain per day for 3 or more consecutive days, it was important to find at what age the calves in the study were typically reaching this level of calf starter consumption. The doubling of calf birth weight was also another important factor to consider before weaning. *TABLE 3* shows the average total starter grain intake per calf per day and per week.

Table 3 Average Total Starter Grain Intake

Age in Weeks	Pounds of Grain Intake Per Day	Pounds of Grain Intake Per Week
1	0.022	0.154
2	0.174	1.218
3	0.356	2.492
4	0.765	5.355
5	1.303	9.121
6	1.881	13.167
7	2.650	18.550
8	3.572	25.004
9	4.275	29.925
10	4.940	34.580
11	5.696	39.872
12	6.100	42.700
13	6.164	43.148
14	6.453	45.171

On average, the calves in the study were consuming 2 pounds of starter grain per day by the age of 6 to 7 weeks. The calves in the study doubled their birth weight by 63 days (9 weeks) of age on average. This means that calves in the study could have been weaned at 9 weeks of age, but many were not weaned until they were 11 or 12 weeks of age. Calves in the study often remained in the hutches up to the point where they were consuming 7 pounds of starter grain per day for well over a week. According to

Holt, S.D (2014), on average the calves in the study were kept in the hutches for 91 days (13 weeks) where their weight gains slowed due to the daily limit of 7 pounds of starter grain that was offered them.

The price at which calf starter grain was most recently purchased for the pre-weaned dairy calves housed at the Caine Dairy was $13.59 per 50 lb. bag. This is equal to $0.27 per lb. The average cost of starter grain per calf from age 1 to 14 weeks is illustrated in *TABLE 4*.

Table 4 Average Cost of Starter Grain per Calf

Age in Weeks	Total Cost of Grain
1	$0.04
2	$0.37
3	$1.04
4	$2.49
5	$4.95
6	$8.51
7	$13.52
8	$20.27
9	$28.35
10	$37.69
11	$48.45
12	$59.98
13	$71.63
14	$83.83

An additional cost of raising pre-weaned dairy calves is the purchase of milk replacer or the cost of using whole milk from the dairy operation for milk feedings. A 50 pound bag of milk replacer ranges in price from $58 to $66, which means per day cost in milk replacer per calf ranges from $1.16 to $1.32 (when calves are fed 4 quarts of milk per day). Once a calf is weaned, milk is no longer consumed by that calf, meaning this daily milk replacer cost is no longer incurred by the dairy operation. Feeding pre-weaned calves is also much more labor intensive than feeding calves that have been weaned. Thus, increased labor is another cost that becomes obsolete once calves have been weaned.

Average weekly weight gain per calf was also calculated. These weight gains are shown in *Table 5*.

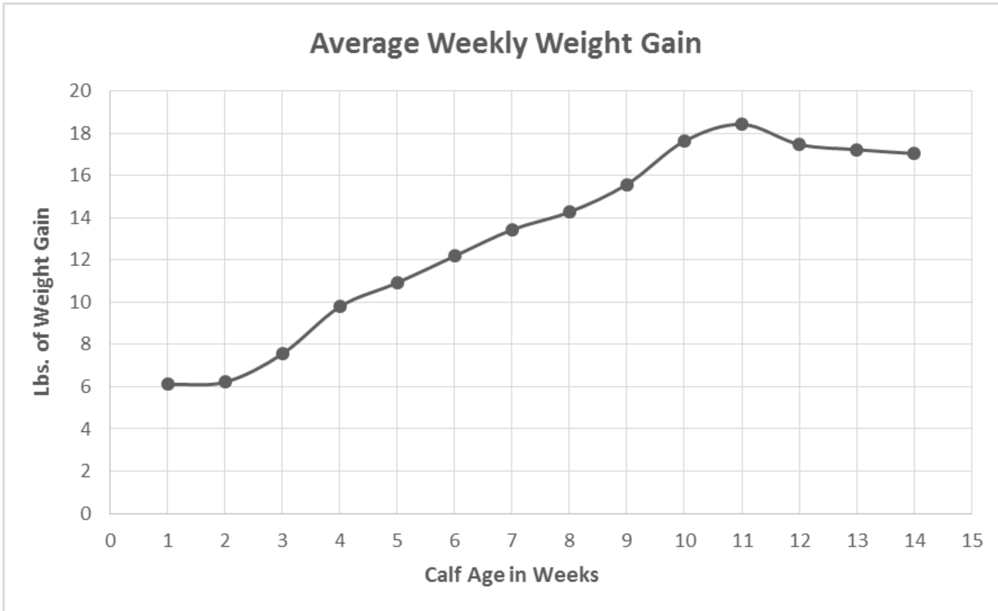
The average weekly weight gain per calf illustrated in *Figure 6* follows the same form of the average physical product (APP) curve in a production function. The x-axis, although labeled as calf age in weeks, can be considered the quantity of variable input since the amount of starter grain consumed increased as the age of the calves in the study increased. Lbs. of weight gain is the output and is represented by the y-axis.

APP (average calf weight gain) in *Figure 6* is increasing at an increasing rate from 1 up to about 6 or 7 weeks of age. At this point APP begins to increase at a decreasing rate. The function eventually reaches a point where APP is at a maximum (11 weeks of age) and the function begins to turn downward. If there is an increase in the use of variable input (starter grain or time spent in the hutches) beyond the point where APP reaches a maximum, then there will be a decrease in APP (average calf weight gained).

Table 5 Average Weekly Weight Gain

Age in Weeks	Weekly Weight Gain in Pounds
1	6.12
2	6.22
3	7.55
4	9.79
5	10.92
6	12.18
7	13.43
8	14.27
9	15.58
10	17.62
11	18.42
12	17.47
13	17.22
14	17.04

Figure 6 Average Weekly Weight Gain



Since most dairy calves are kept by a dairy operation to replenish their herds instead of being sold, very little data exists on dairy calf prices. For this reason the cost minimization model that was created used dairy calf prices from \$0.10 to \$2.00 per pound, which is useful because dairy calf prices do fluctuate. These prices are listed on the y-axis of the model (*Table 6*).

Table 6 Cost Minimization Model Using Calf Values and Weeks of Age

Dairy Calf Price $/Lb.														
$2.00	$ 12.23	$ 12.44	$ 15.11	$ 19.57	$ 21.83	$ 24.37	$ 26.86	$ 28.54	$ 31.15	$ 35.25	$ 36.83	$ 34.94	$ 34.44	$ 34.07
$1.90	$ 11.62	$ 11.81	$ 14.35	$ 18.59	$ 20.74	$ 23.15	$ 25.52	$ 27.12	$ 29.60	$ 33.49	$ 34.99	$ 33.19	$ 32.72	$ 32.37
$1.80	$ 11.01	$ 11.19	$ 13.60	$ 17.61	$ 19.65	$ 21.93	$ 24.17	$ 25.69	$ 28.04	$ 31.72	$ 33.15	$ 31.45	$ 31.00	$ 30.67
$1.70	$ 10.40	$ 10.57	$ 12.84	$ 16.63	$ 18.56	$ 20.71	$ 22.83	$ 24.26	$ 26.48	$ 29.96	$ 31.31	$ 29.70	$ 29.28	$ 28.96
$1.60	$ 9.78	$ 9.95	$ 12.09	$ 15.66	$ 17.47	$ 19.49	$ 21.49	$ 22.83	$ 24.92	$ 28.20	$ 29.47	$ 27.95	$ 27.55	$ 27.26
$1.50	$ 9.17	$ 9.33	$ 11.33	$ 14.68	$ 16.38	$ 18.28	$ 20.14	$ 21.41	$ 23.37	$ 26.44	$ 27.63	$ 26.21	$ 25.83	$ 25.55
$1.40	$ 8.56	$ 8.71	$ 10.58	$ 13.70	$ 15.28	$ 17.06	$ 18.80	$ 19.98	$ 21.81	$ 24.67	$ 25.78	$ 24.46	$ 24.11	$ 23.85
$1.30	$ 7.95	$ 8.08	$ 9.82	$ 12.72	$ 14.19	$ 15.84	$ 17.46	$ 18.55	$ 20.25	$ 22.91	$ 23.94	$ 22.71	$ 22.39	$ 22.15
$1.20	$ 7.34	$ 7.46	$ 9.07	$ 11.74	$ 13.10	$ 14.62	$ 16.12	$ 17.13	$ 18.69	$ 21.15	$ 22.10	$ 20.96	$ 20.67	$ 20.44
$1.10	$ 6.73	$ 6.84	$ 8.31	$ 10.76	$ 12.01	$ 13.40	$ 14.77	$ 15.70	$ 17.14	$ 19.39	$ 20.26	$ 19.22	$ 18.94	$ 18.74
$1.00	$ 6.12	$ 6.22	$ 7.55	$ 9.79	$ 10.92	$ 12.18	$ 13.43	$ 14.27	$ 15.58	$ 17.62	$ 18.42	$ 17.47	$ 17.22	$ 17.04
$0.90	$ 5.50	$ 5.60	$ 6.80	$ 8.81	$ 9.83	$ 10.97	$ 12.09	$ 12.84	$ 14.02	$ 15.86	$ 16.58	$ 15.72	$ 15.50	$ 15.33
$0.80	$ 4.89	$ 4.97	$ 6.04	$ 7.83	$ 8.73	$ 9.75	$ 10.74	$ 11.42	$ 12.46	$ 14.10	$ 14.73	$ 13.98	$ 13.78	$ 13.63
$0.70	$ 4.28	$ 4.35	$ 5.29	$ 6.85	$ 7.64	$ 8.53	$ 9.40	$ 9.99	$ 10.90	$ 12.34	$ 12.89	$ 12.23	$ 12.06	$ 11.93
$0.60	$ 3.67	$ 3.73	$ 4.53	$ 5.87	$ 6.55	$ 7.31	$ 8.06	$ 8.56	$ 9.35	$ 10.57	$ 11.05	$ 10.48	$ 10.33	$ 10.22
$0.50	$ 3.06	$ 3.11	$ 3.78	$ 4.89	$ 5.46	$ 6.09	$ 6.71	$ 7.14	$ 7.79	$ 8.81	$ 9.21	$ 8.74	$ 8.61	$ 8.52
$0.40	$ 2.45	$ 2.49	$ 3.02	$ 3.91	$ 4.37	$ 4.87	$ 5.37	$ 5.71	$ 6.23	$ 7.05	$ 7.37	$ 6.99	$ 6.89	$ 6.81
$0.30	$ 1.83	$ 1.87	$ 2.27	$ 2.94	$ 3.28	$ 3.66	$ 4.03	$ 4.28	$ 4.67	$ 5.29	$ 5.53	$ 5.24	$ 5.17	$ 5.11
$0.20	$ 1.22	$ 1.24	$ 1.51	$ 1.96	$ 2.18	$ 2.44	$ 2.69	$ 2.85	$ 3.12	$ 3.52	$ 3.68	$ 3.49	$ 3.44	$ 3.41
$0.10	$ 0.61	$ 0.62	$ 0.76	$ 0.98	$ 1.09	$ 1.22	$ 1.34	$ 1.43	$ 1.56	$ 1.76	$ 1.84	$ 1.75	$ 1.72	$ 1.70
Age in Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Starter Cost	$0.04	$0.37	$1.04	$2.49	$4.95	$8.51	$13.52	$20.27	$28.35	$37.69	$48.45	$59.98	$71.63	$83.83

Several steps were taken to calculate the values in the body of the model. First, the average daily weight gain per calf in the study was calculated for weekly age periods. This average daily weight gain per calf was then multiplied by 7 in order to find the average weekly weight gain per calf. Next, this weekly average weight gain per calf was multiplied by the per pound dairy calf prices in ten cent increments starting at $0.10 and ending at $2.00 per pound. This produced 20 values for each “age in weeks” period. Essentially, each of these 20 values listed in each weekly column represents a value given an assumed price of dairy calves per pound. For example, if a calf is 4 weeks old and the current dairy calf price is $1.00/lb. then the value gained from keeping that calf in a hutch and feeding it calf starter is $9.79, assuming that all other costs are fixed (i.e., $9.79 is the cross-section of 4 weeks and $1.00/lb. in the model).

The cost of starter ($0.27/lb.) is also represented in the model just below the x-axis. All other costs associated with raising dairy calves were considered fixed. Continuing with the example in the previous paragraph, the average cost of starter to raise a calf to 4 weeks of age is $2.49. In this case, the value gained from keeping a calf in the hutches and feeding it starter ($9.79), outweighs the cost of doing so ($2.49). As calf age in weeks increased, starter consumption also increased. This means that in order to continue to feed a calf starter (keeping it in a hutch) to make economic sense, the value gained has to continue to be greater than the cost of feeding starter. Some things that can help increase this value gained are: 1) an increase in the price of dairy calves, 2) a decrease in the price of starter grain, or 3) an increase in the average amount of weight gained per week.

If a dairy producer were to use this model, how could he tell when it is no longer profitable to continue feeding a calf starter? In other words, when should he wean his calves? By referring to the *Table 6* model, this answer can be determined. Using the cost of starter grain purchased at the Caine Dairy ($0.27/lb.), a line has been drawn and some values have been highlighted in yellow. The yellow cells indicate a time when the cost is just greater than (or equal to) the value and the dairy producer should have stopped feeding the animal a week earlier (the value gained becomes less than cost). The 9 week column is highlighted in blue since this was the average age the calves in the study were doubling their birth weight.

The first value highlighted in yellow in the model occurs at 3 weeks of age and dairy calf price of $0.10/lb., since starter cost at age 3 weeks is $1.04 which is between the values $0.76 and $1.51 in the model. This means that with the cost of starter at $0.27/lb., a calf that is 3 weeks old, and a dairy calf price of about $0.15/lb. (interpolating between $0.10 and $0.20/lb.), the cost of feeding a calf starter exceeds the value gained from feeding it starter. This type of sensitivity analysis can be conducted with different calf starter prices as well. The producer would have to simply multiply the average amount of starter consumed on a weekly basis per calf, by the price per pound of calf starter.

Interestingly, the costs, and therefore the values, necessary to make continuing to feed a calf starter begin to accelerate greatly between weeks of age 6 and 7. This correlates with the inflection point illustrated in *Figure 6* and also correlates with the age at which the calves in the study were starting to consume 2 pounds of starter per day; all of these are indications that the optimal time to wean the calves in the study was at between 6 and 7 weeks of age. But since the calves in the study were not doubling their birth weight until 9 weeks of age on average, the calves should be weaned between 7 and 9 weeks of age.

Three additional cost minimization tables were created, Tables 7, 8, and 9. These tables are similar to Table 6 in that calf values make up the body of the tables, and they differ from Table 6 in that calf age is no only measured in weeks but in days as well. These three tables show the daily cost incurred and the daily value gained from feeding starter to calves age 7 weeks to 10 weeks, allowing a producer to more accurately estimate the cost incurred and value gained from each additional day that starter is fed to a pre-weaned calf.

Table 7 Cost Minimization Model Using Calf Values and 7 to 8 Weeks of Age

Dairy Calf Price $/Lb.									
	$2.00	$ 26.86	$ 26.86	$ 26.86	$ 26.86	$ 26.86	$ 26.86	$ 26.86	$ 26.86
	$1.90	$ 25.52	$ 25.52	$ 25.52	$ 25.52	$ 25.52	$ 25.52	$ 25.52	$ 25.52
	$1.80	$ 24.17	$ 24.17	$ 24.17	$ 24.17	$ 24.17	$ 24.17	$ 24.17	$ 24.17
	$1.70	$ 22.83	$ 22.83	$ 22.83	$ 22.83	$ 22.83	$ 22.83	$ 22.83	$ 22.83
	$1.60	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49
	$1.50	$ 20.14	$ 20.14	$ 20.14	$ 20.14	$ 20.14	$ 20.14	$ 20.14	$ 20.14
	$1.40	$ 18.80	$ 18.80	$ 18.80	$ 18.80	$ 18.80	$ 18.80	$ 18.80	$ 18.80
	$1.30	$ 17.46	$ 17.46	$ 17.46	$ 17.46	$ 17.46	$ 17.46	$ 17.46	$ 17.46
	$1.20	$ 16.12	$ 16.12	$ 16.12	$ 16.12	$ 16.12	$ 16.12	$ 16.12	$ 16.12
	$1.10	$ 14.77	$ 14.77	$ 14.77	$ 14.77	$ 14.77	$ 14.77	$ 14.77	$ 14.77
	$1.00	$ 13.43	$ 13.43	$ 13.43	$ 13.43	$ 13.43	$ 13.43	$ 13.43	$ 13.43
	$0.90	$ 12.09	$ 12.09	$ 12.09	$ 12.09	$ 12.09	$ 12.09	$ 12.09	$ 12.09
	$0.80	$ 10.74	$ 10.74	$ 10.74	$ 10.74	$ 10.74	$ 10.74	$ 10.74	$ 10.74
	$0.70	$ 9.40	$ 9.40	$ 9.40	$ 9.40	$ 9.40	$ 9.40	$ 9.40	$ 9.40
	$0.60	$ 8.06	$ 8.06	$ 8.06	$ 8.06	$ 8.06	$ 8.06	$ 8.06	$ 8.06
	$0.50	$ 6.71	$ 6.71	$ 6.71	$ 6.71	$ 6.71	$ 6.71	$ 6.71	$ 6.71
	$0.40	$ 5.37	$ 5.37	$ 5.37	$ 5.37	$ 5.37	$ 5.37	$ 5.37	$ 5.37
	$0.30	$ 4.03	$ 4.03	$ 4.03	$ 4.03	$ 4.03	$ 4.03	$ 4.03	$ 4.03
	$0.20	$ 2.69	$ 2.69	$ 2.69	$ 2.69	$ 2.69	$ 2.69	$ 2.69	$ 2.69
	$0.10	$ 1.34	$ 1.34	$ 1.34	$ 1.34	$ 1.34	$ 1.34	$ 1.34	$ 1.34
	Age in Weeks	7	7 & 1day	7 & 2days	7 & 3days	7 & 4days	7 & 5days	7 & 6days	8
	Starter Cost	$13.52	$14.48	$15.45	$16.41	$17.38	$18.34	$19.31	$20.27

Table 8 Cost Minimization Model Using Calf Values and 8 to 9 Weeks of Age

	$2.00	$ 28.54	$ 28.54	$ 28.54	$ 28.54	$ 28.54	$ 28.54	$ 28.54	$ 28.54
	$1.90	$ 27.12	$ 27.12	$ 27.12	$ 27.12	$ 27.12	$ 27.12	$ 27.12	$ 27.12
	$1.80	$ 25.69	$ 25.69	$ 25.69	$ 25.69	$ 25.69	$ 25.69	$ 25.69	$ 25.69
	$1.70	$ 24.26	$ 24.26	$ 24.26	$ 24.26	$ 24.26	$ 24.26	$ 24.26	$ 24.26
	$1.60	$ 22.83	$ 22.83	$ 22.83	$ 22.83	$ 22.83	$ 22.83	$ 22.83	$ 22.83
	$1.50	$ 21.41	$ 21.41	$ 21.41	$ 21.41	$ 21.41	$ 21.41	$ 21.41	$ 21.41
	$1.40	$ 19.98	$ 19.98	$ 19.98	$ 19.98	$ 19.98	$ 19.98	$ 19.98	$ 19.98
Dairy Calf Price $/Lb.	$1.30	$ 18.55	$ 18.55	$ 18.55	$ 18.55	$ 18.55	$ 18.55	$ 18.55	$ 18.55
	$1.20	$ 17.13	$ 17.13	$ 17.13	$ 17.13	$ 17.13	$ 17.13	$ 17.13	$ 17.13
	$1.10	$ 15.70	$ 15.70	$ 15.70	$ 15.70	$ 15.70	$ 15.70	$ 15.70	$ 15.70
	$1.00	$ 14.27	$ 14.27	$ 14.27	$ 14.27	$ 14.27	$ 14.27	$ 14.27	$ 14.27
	$0.90	$ 12.84	$ 12.84	$ 12.84	$ 12.84	$ 12.84	$ 12.84	$ 12.84	$ 12.84
	$0.80	$ 11.42	$ 11.42	$ 11.42	$ 11.42	$ 11.42	$ 11.42	$ 11.42	$ 11.42
	$0.70	$ 9.99	$ 9.99	$ 9.99	$ 9.99	$ 9.99	$ 9.99	$ 9.99	$ 9.99
	$0.60	$ 8.56	$ 8.56	$ 8.56	$ 8.56	$ 8.56	$ 8.56	$ 8.56	$ 8.56
	$0.50	$ 7.14	$ 7.14	$ 7.14	$ 7.14	$ 7.14	$ 7.14	$ 7.14	$ 7.14
	$0.40	$ 5.71	$ 5.71	$ 5.71	$ 5.71	$ 5.71	$ 5.71	$ 5.71	$ 5.71
	$0.30	$ 4.28	$ 4.28	$ 4.28	$ 4.28	$ 4.28	$ 4.28	$ 4.28	$ 4.28
	$0.20	$ 2.85	$ 2.85	$ 2.85	$ 2.85	$ 2.85	$ 2.85	$ 2.85	$ 2.85
	$0.10	$ 1.43	$ 1.43	$ 1.43	$ 1.43	$ 1.43	$ 1.43	$ 1.43	$ 1.43
	Age in Weeks	8	8 & 1day	8 & 2days	8 & 3days	8 & 4days	8 & 5days	8 & 6days	9
	Starter Cost	$20.27	$21.42	$22.58	$23.73	$24.89	$26.04	$27.20	$28.35

Table 9 Cost Minimization Model Using Calf Values and 9 to 10 Weeks of Age

Dairy Calf Price $/Lb.									
	$2.00	$ 31.15	$ 31.15	$ 31.15	$ 31.15	$ 31.15	$ 31.15	$ 31.15	$ 31.15
	$1.90	$ 29.60	$ 29.60	$ 29.60	$ 29.60	$ 29.60	$ 29.60	$ 29.60	$ 29.60
	$1.80	$ 28.04	$ 28.04	$ 28.04	$ 28.04	$ 28.04	$ 28.04	$ 28.04	$ 28.04
	$1.70	$ 26.48	$ 26.48	$ 26.48	$ 26.48	$ 26.48	$ 26.48	$ 26.48	$ 26.48
	$1.60	$ 24.92	$ 24.92	$ 24.92	$ 24.92	$ 24.92	$ 24.92	$ 24.92	$ 24.92
	$1.50	$ 23.37	$ 23.37	$ 23.37	$ 23.37	$ 23.37	$ 23.37	$ 23.37	$ 23.37
	$1.40	$ 21.81	$ 21.81	$ 21.81	$ 21.81	$ 21.81	$ 21.81	$ 21.81	$ 21.81
	$1.30	$ 20.25	$ 20.25	$ 20.25	$ 20.25	$ 20.25	$ 20.25	$ 20.25	$ 20.25
	$1.20	$ 18.69	$ 18.69	$ 18.69	$ 18.69	$ 18.69	$ 18.69	$ 18.69	$ 18.69
	$1.10	$ 17.14	$ 17.14	$ 17.14	$ 17.14	$ 17.14	$ 17.14	$ 17.14	$ 17.14
	$1.00	$ 15.58	$ 15.58	$ 15.58	$ 15.58	$ 15.58	$ 15.58	$ 15.58	$ 15.58
	$0.90	$ 14.02	$ 14.02	$ 14.02	$ 14.02	$ 14.02	$ 14.02	$ 14.02	$ 14.02
	$0.80	$ 12.46	$ 12.46	$ 12.46	$ 12.46	$ 12.46	$ 12.46	$ 12.46	$ 12.46
	$0.70	$ 10.90	$ 10.90	$ 10.90	$ 10.90	$ 10.90	$ 10.90	$ 10.90	$ 10.90
	$0.60	$ 9.35	$ 9.35	$ 9.35	$ 9.35	$ 9.35	$ 9.35	$ 9.35	$ 9.35
	$0.50	$ 7.79	$ 7.79	$ 7.79	$ 7.79	$ 7.79	$ 7.79	$ 7.79	$ 7.79
	$0.40	$ 6.23	$ 6.23	$ 6.23	$ 6.23	$ 6.23	$ 6.23	$ 6.23	$ 6.23
	$0.30	$ 4.67	$ 4.67	$ 4.67	$ 4.67	$ 4.67	$ 4.67	$ 4.67	$ 4.67
	$0.20	$ 3.12	$ 3.12	$ 3.12	$ 3.12	$ 3.12	$ 3.12	$ 3.12	$ 3.12
	$0.10	$ 1.56	$ 1.56	$ 1.56	$ 1.56	$ 1.56	$ 1.56	$ 1.56	$ 1.56
	Age in Weeks	9	9 & 1day	9 & 2days	9 & 3days	9 & 4days	9 & 5days	9 & 6days	10
	Starter Cost	$28.35	$29.68	$31.02	$32.35	$33.69	$35.02	$36.36	$37.69

CHAPTER VI

CONCLUSION

The minimization of cost in raising dairy calves, while preserving and promoting overall calf health, will be of utmost importance in future profitable dairy operations. Although many factors that affect calf growth and health cannot be easily controlled by the dairy producer, the necessity of monitoring calf starter intake and weaning calves in a timely manner was determined and illustrated. The objectives of the study were to: 1) develop a model which minimizes cost of starter feed (which is a variable controlled by the dairy producer), 2) use the model developed under objective 1) to find the breakeven point (where the cost of an input is less than or equal to the value gained from that input) and conduct sensitivity analysis with respect to this point, 3) define in detail the econometric problems that existed in Holt's study, and 4) find and implement solutions to the econometric problems that existed in that study.

Through this study it was shown empirically that the George B. Caine Dairy at Utah State University could minimize costs in calf raising by weaning their calves earlier. The development of a calf's rumen before weaning is vital and normally happens once a calf begins consuming 2 pounds of starter per day for at least 3 consecutive days. This level of consumption was reached by the calves in the study between 6 and 7 weeks of age, while the calves doubled their birth weight by 63 days (9 weeks) of age on average. The average age at which the calves in the study were weaned was 13 weeks.

The cost minimization model (*Figure 7*) illustrates different points for the dairy calf operation at the Caine Dairy where the starter grain costs were less than the value of the calf gain. This model shows at which points the cost of continuing to feed a calf starter grain exceeds the value of doing the same. Once the calves reached 6 to 7 weeks of age, the cost of feeding them starter began to exceed the value that was added if dairy calf prices were about $0.80/lb. or less. By the time the calves reached the age of 10 weeks, dairy calf prices would have had to have been well over $2.00/lb. in order for the value added by feeding them starter to exceed the cost.

The average cost of calf starter to raise a calf from birth to 13 weeks of age (the average age of weaning for the calves in the study) was $71.63. The average cost of calf starter to raise a calf from birth to 7 weeks of age (the point where the calves in the study were consuming enough grain to be weaned) was $13.52. This difference (between the cost of calf starter from birth to 13 weeks and the cost of starter from birth to 7 weeks) is $58.11 per calf. Considering there were 98 calves included in the study, this was a total average starter cost difference of $5,694.78 between raising all of the calves in the study from birth to 13 weeks of age and raising them from birth to 7 weeks of age. This is excluding the milk costs, extra labor required for pre-weaned calf feeding, and the starter cost for calves that were not included in the study who were likely also weaned at about 13 weeks of age.

The econometric problems that existed in the previous study were identified and solutions to these problems were implemented in Chapter 5 of this study. The panel data contained multicollinearity, hetereoskedasticity, and serial correlation. Multicollinearity was minimized by dropping the variable temperature PM from the equation and combining the variables intake AM and intake PM. Heteroskedasticity and serial correlation were eliminated by estimating the equation with Newey-West standard errors. The result was an equation that was used to make inferences, such as the amount of weight gain expected given a certain amount of starter intake, that were useful in meeting the remaining two objectives.

STUDY LIMITATIONS AND FUTURE RESEARCH

One of the limitations of the study was the inability to acquire data on dairy calf prices to use for the cost minimization model. Although this problem was resolved by using a range of dairy calf prices, a more accurate estimation for the price of dairy calves would have been helpful in analyzing costs.

Another limitation was that some data were collected twice per day (all weather related data, starter intake, and score), and other data were only collected once per week (calf weight and hip height). Thus the data that was gathered daily had to be summed into weekly data causing some loss of accuracy.

Because so little research has been done on the effect that weather related conditions have on dairy calf growth, it would be of benefit for dairy producers to have more information on this topic. There are numerous studies that have been conducted on weather conditions and their effect on adult dairy cattle, while the effect of weather conditions on dairy calves is nearly non-existent. Since calf management practices ultimately impact milk productivity and reproductive performance during a heifer's lifetime, more importance should be placed on the study of the effect of weather conditions on dairy calves.

Finally, a similar study using a larger sample size (including more calves) would be helpful for future research. This would produce a more accurate data set and help supplement the findings of this study.

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