Implications of Cow Nutrition on Whole-Farm Profitability of Minnesota Dairy Farms

A Thesis

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Chapter 1

Introduction

Fluctuating market conditions have caused dairy farmers to struggle financially over the past several years. Large variations in milk prices occurred recently with record high prices reported in 2014 along with record-lows in 2019 and 2020. Farmers desire to manage their milk price and costs under these circumstances, increasing their interest in making their operations more efficient. Farmers are seeking ways to remain profitable during low milk prices to stay in business for the long term.

Feed costs account for a large portion of a dairy's expenses, accounting for just over 45% of total cost of production in the U.S. in 2019 (USDA-ERS, 2020). A farm's ability to survive from year to year is largely due to its ability to manage these costs while considering animal health and milk yield. The feeding decision is complicated for producers. Nutritionists and farmers want to improve cow health and increase milk output, and many times that option is not the lowest cost feed ration. Therefore, farmers have to evaluate the tradeoff between cow performance and feed cost over time.

Greater nutrients in the feed cost more and often lead to greater milk production (NRC, 2001). Because of this, the lowest cost ration results in lower milk output, while the highest cost ration results in higher milk output. When formulating rations, the margin between milk revenue and feed cost must be considered to maximize profitability. Smaller farms that are able to decrease their feed costs by using homegrown feeds or grazing systems are able to lower their ration costs. This, in turn, lowers their milk yield; however, they are able to maintain or increase their component levels (milk fat and

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protein concentrations in milk), achieving higher premiums for milk quality. With so many aspects playing a role in both the revenue and cost sides to farm profitability, it is important to recognize that there are different strategies that can lead to long-term profitability, rather than a one-size-fits-all for everyone.

Biological and economic factors of dairy production are rarely tied together, as it is hard to match production data directly with financial data. Matching production data with financial data, including feed data, allows one to fully analyze long-term profitability given a multitude of cow-level management and herd-level financial characteristics. Roberts (2019) was one of the first studies to pull this type of data together and found that higher concentrations of fat and protein in milk led to an increased likelihood of dairy farm resiliency. From a biological perspective, it is well known that cow nutrition plays a large role in these factors. Minnesota is home to a large number of milk processing cooperatives that still pay premiums for milk quality components, rather than just yield. By studying the individual impacts of feeding decisions on cow-level performance and using those results in an analysis of financial resiliency, dairy farmers can be provided with recommendations on common feeding strategies that have resulted in increased profitability and financial resiliency over time.

Considering the feeding decision will be important to this analysis. The feeding decision is the ration choice determined by farmers and nutritionists to feed to their cows. This nutritional aspect of a farm's profitability can be attributed to the types of feeds utilized, the combinations and balancing of the feeds, and the management of the ration. These three considerations play a major role in how the feeding decision and cow nutrition affect a dairy farm's financial resiliency. By increasing the detail of the feeding

decision while analyzing other factors influencing resilient farms, the effect of the

feeding decision and cow nutrition on whole-farm profitability can be measured.

Chapter 2

Research Objectives

The objective of this study is to understand how the characteristics of cow nutrition affect whole-farm profitability of Minnesota dairy farms over time. This analysis used a two-step approach to identify common characteristics of the feeding decision among financially resilient farms. First, the feeding decision was analyzed to identify common feedstuffs utilized in dairy rations that have an impact on energy corrected milk (ECM). This builds upon Roberts' (2019) study, which found that farms with lower milk yields and higher milk fat and protein concentrations were commonly identified as resilient farms. The feeding decision has one of the largest impacts on milk yield and component levels. Therefore, the feed factors that impact milk production at a cow level were identified and evaluated. A panel[1] fixed-effects regression was used to capture the biological and genetic effects of feeding the same ration to all cows within a herd and observing varying production outcomes within and across farms in the sample.

The information compiled in this first step was used as explanatory variables in a panel between-effects regression to determine how feeding decision characteristics affect farm profitability and resiliency. Again, the analysis was completed at the cow level, controlling for within-herd and across-farm variation. Additional explanatory variables included human resource factors (age of principal operator, second generation operator, education, and hired labor per cow), herd structure factors (herd size, acres per cow, and

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[1] "Panel" refers to the dataset having repeated observations within the cow level and the farm level.

percent of crop acres owned), financial indicators (debt to asset ratio, working capital per cow, and interest expense per cow), and animal health indicators (ECM, death rate, and cull rate). The results of the second step of this analysis identified farm and cow-level characteristics that directly impact dairy farm resiliency in Minnesota.

Chapter 3

Literature Review

3.1   Science of Milk and Component Synthesis

Cow nutrition has a large impact on milk production. Increased milk yield as well as increased milk components leads to greater revenue and in turn greater profitability (Buza et al., 2014; Krpálková et al., 2014; Roberts, 2019). Previous work at the University of Minnesota studied the factors influencing resilient dairy farms, or farms who were profitable over the long term, and found that milk components were significant predictors of resilient Minnesota dairy farms (Roberts, 2019). Dairies with higher concentrations of fat and protein in their milk were found to be more resilient rather than those with a high milk yield per cow (Roberts, 2019). This was likely because higher milk fat and protein levels often lead to premiums received by dairy farmers, as higher component levels are desired by processors to make dairy products outside of fluid milk. Because of this, milk components are analyzed in conjunction with milk yield in this study, rather than milk yield separately, to understand dairy farm resiliency from the nutrition perspective.

Milk components are managed in various ways, which include nutrition, genetics, and herd management. Fifty-five percent of the variation in milk component levels is caused by genetics, meanwhile 45% of the variation in milk composition is caused by the environment, including nutrition and feed management (Grant and Kononoff, 2007). When considering genetics, selecting for sires that improve milk fat and protein yields

can improve milk component levels in the next generation. On the environmental side, one of the easiest ways to manage milk components is the feeding decision.

Milk production is affected by many aspects of dairy cattle nutrition, including dry matter intake (DMI), energy consumption, crude protein (CP), fiber, non-fiber carbohydrates (NFC), fats, vitamins, and minerals. Dry matter intake can increase milk production, as a cow consuming more feed converts the increased nutrients into greater milk yield (Bach et al, 2020). The other nutrients found in feedstuffs are converted to energy to be used within the cow for four purposes: growth, maintenance, lactation, and reproduction. Each nutrient plays a vital role in the synthesis of milk yield, fat, and protein, as each nutrient has a different function within the cow or is converted to the nutrients found in milk. Thus, feeds that are higher in energy can be assumed to result in higher milk production.

Carbohydrates consumed by the cow are converted to volatile fatty acids (VFA) by rumen microbes (NRC, 2001; Heinrichs et al., 2016). These VFAs include butyrate, acetate, and propionate. Butyrate is converted to beta-hydroxybutyrate (BHB) in the rumen wall tissue (Heinrichs et al., 2016). Both BHB and acetate are synthesized by the mammary cells into milk fat, half of which is excreted in milk (Heinrichs et al., 2016). Meanwhile, propionate is converted to glucose in the liver, which later gets made into lactose produced by the cow (NRC, 2001; Heinrichs et al., 2016).

Protein consumed by the cow is composed of rumen degradable protein (RDP) and rumen undegradable protein (RUP; NRC, 2001). Rumen microbes convert RDP into dietary protein that can be used by the cow (NRC, 2001). Both the converted RDP and RUP then move to the abomasum, where they are denatured due to the lower pH level.

The denatured protein later becomes free amino acids, which are synthesized into milk proteins in the mammary cells and produced by the cow (Heinrichs et al., 2016).

Among the nutrients in dairy cattle feeds, certain nutrients have been found to improve milk yield and components more than others. Daniel et al. (2016) performed a meta-analysis of studies, finding that an increase in metabolizable protein (MP) causes an increase in DMI with diminishing marginal returns. This means that increasing MP can increase DMI up to a certain point. MP and net energy (NE) in a dairy ration show positive effects on milk components (Daniel et al., 2016). In addition, a symposium by Bach et al. (2020) proved that NE consumed above maintenance requirements has a positive relationship with milk energy secretion.

Most recently, studies have shown that fatty acids formed by the mammary gland, commonly called de novo fatty acids, have a significant impact on bulk tank fat and protein tests (Barbano et al., 2014; Woolpert et al., 2016). Higher levels of de novo fatty acids increase milk fat test (Barbano et al., 2014), milk fat yield (Woolpert et al., 2016), and true protein content and yield (Woolpert et al., 2016). De novo fatty acids can be increased through feeding forages (Barbano, 2014), increasing bunk space per cow, and lowering stocking density (Woolpert, 2016). Sova et al. (2013) also found that increasing bunk space increased milk fat concentration in freestall herds.

Although most studies focus on improving milk production, ration formulation can be adjusted to achieve target components in conjunction with optimizing milk yield (Dado et al., 1993; Mertens and Dado, 1993). Hillers et al. (1979) noted the importance of milk composition rather than milk yield for a dairy's profitability. Mertens and Dado (1993) created a system of equations for ration formulation to determine the amounts of

feeds along with their absorbed nutrient requirements for different combinations of milk components. Sutton (1989) reported milk fat concentration was affected by ration composition, especially while evaluating the roughages fed. Milk fat is the most sensitive to changes in the diet and can be altered over a large range of approximately 3 percentage points, meanwhile protein can be altered over a smaller range of approximately one-fifth of that of fat and lactose by barely at all (Sutton, 1989).

3.2   Science of the Feeding Decision

Balancing the ration is a crucial part of managing a dairy herd. Each nutrient must be balanced across feedstuffs within optimal ranges in a manner to optimize milk production while considering dairy cattle health. Rations are managed to maximize milk production or components and minimize health risks, while simultaneously striving to keep feed costs as low as possible.

While maintaining a balanced ration, keeping a good roughage to concentrate ratio is critical. Too much roughage in the diet with too little concentrate can cause milk production to decrease. Cows that consume 20% of dietary dry matter (DM) as feed concentrates (e.g. corn, soybeans, dried distillers grains, cottonseed, etc.) produce less milk than cows who consume concentrates within the range of 40-60% dietary DM (NRC, 2001; Weiss and Shockey, 1991). The National Research Council (NRC; 2001) reports that DMI increases for cows that consume higher concentrate levels up to about 60%.

Low roughage diets can cause milk fat depression (MFD), a decrease in milk fat of 0.2% or more (Thompson and Amaral-Phillips, n.d.), but the response varies widely

depending on many factors, especially the source of carbohydrates in the concentrates (Sutton, 1989). An Extension article by Grant and Kononoff (2007) states that feeding 40-50% forage dry matter is the lowest amount a cow should be fed to prevent low milk fat levels. Some literature suggests that feeding 50% or more of the diet as forages keeps milk fat concentrations fairly constant; however, decreasing forages to lower than 50% of the diet causes variable decreases in milk fat concentration (Journet and Chilliard, 1985; Sutton, 1989; Thomas and Martin, 1988). A proper forage fiber level in the diet assists in stimulating rumination, keeping rumen pH at adequate levels for the breakdown of feeds. Feeding too high of starch, or NFC, can lead to MFD of one percentage point or more while milk protein levels can increase by 0.2-0.3 percentage points (Grant and Kononoff, 2007). Forage dry matter, consisting of 65% of feed or higher, must be of high quality to prevent energy deficiencies to cattle, which in turn lowers milk protein levels (Grant and Kononoff, 2007).

Different feedstuffs have shown impacts on milk fat and protein concentrations. Sutton (1989) dives deep into a review of literature on the impact of the feeding decision on altering milk composition; however, this has not been updated in thirty years. Sutton (1989) reported a summary of effective and potentially useful ways to alter both milk fat and protein concentrations. Sutton (1989) recommends adjusting the dietary fiber concentration using a roughage index, the type of carbohydrate fed in the concentrates, and the frequency of meals for concentrates in low roughage diets to alter milk fat concentration. Altering milk protein concentration is more difficult than milk fat, but Sutton (1989) reports possible options include altering the forage to concentrate ratio and the type of carbohydrate fed in the concentrates; however, responses are inconsistent.

Rolled barley and ground corn result in similar milk fat concentration levels when fed in diets with adequate roughage (DePeters and Taylor, 1987; Sutton et al., 1980; Sutton, 1989). However, in low roughage diets, the milk fat depression is more severe in diets with rolled barley rather than diets with ground corn (Sutton et al., 1980; Sutton, 1989). In conventional diets, oats cause a lower milk fat concentration when compared to barley (Martin and Thomas, 1988; Sutton, 1989). Low starch and high fiber by-products, such as corn gluten feed, sugar beet pulp, and citrus pulp, have been reported to greatly decrease MFD that occurs with large amounts of high starch concentrates (MacGregor et al., 1983; Sutton et al., 1987; Sutton, 1989). Although, these feeds have little effect on milk fat concentration when milk fat levels are normal (Mayne and Gordon, 1984; Phipps et al., 1987; Sutton, 1989).

Altering milk protein concentration has shown inconsistent responses (Sutton, 1989). In one study, when the concentrate:hay ratio increased from 60:40 to 90:10, milk protein concentration was reported to have increased by 0.4 percentage points with ground corn but not with rolled barley (Sutton et al., 1980; Sutton, 1989). In contrast, Flatt et al. (1969) reported that milk protein concentration did not change with ground corn from a similar increase in the concentrate:hay ratio, as demonstrated by Sutton (1989). In conventional diets, oats cause a lower milk protein concentration by 0.2 percentage points when compared to barley (Martin and Thomas, 1988; Sutton, 1989).

3.3   Economics of the Feeding Decision

Roberts (2019) studied the impact of herd management and farm financials on dairy farm resiliency. Resilient dairy farms are defined as those that performed in the top

25% of farms based on their adjusted net farm income (NFI) ratio or rate of return on assets (RROA) for the majority of the years studied (Roberts, 2019). Roberts' (2019) study demonstrated resilient farms managed both cow health and financials to build long-term profitability. This research from the University of Minnesota did not deeply examine the impact of cow nutrition on dairy farm resiliency. With detailed feed information, the current study further analyzes the effect of nutrition on long-term profitability of Minnesota dairy farms.

Research on the economics of nutrition, specifically nutrition's impact on dairy farm resiliency or profitability, has not been widely studied. Income over feed cost (IOFC) is a common measurement used to look at the effectiveness of a dairy's nutrition and ration management, as it accounts for the volatility in the feed markets (Buza et al., 2014; Vibart et al., 2012). The IOFC is the gross income from a farm minus its total feed cost, so it does not capture the full impact of profitability on the farm. Buza et al. (2014) found that ration composition with higher quality feeds generated higher milk yield and IOFC. In addition, commodity by-products, intermediate levels of forage cost, and higher levels of feed cost per cow per day resulted in higher milk yield and IOFC (Buza et al., 2014). Similarly, a survey by Steuernagel (1983), as described in the symposium review by Bath (1985), found that low-producing cows fed the lowest feed cost per day from the least amount of grain concentrates had the lowest IOFC per cow; meanwhile, the high-producing cows fed the highest feed cost per cow from the highest amount of grain concentrates had the greatest IOFC. In contrast, Vibart et al. (2012) found that cows with higher stocking rates and higher amounts of dry matter fed had similar IOFC to those with lower stocking rates and lower amounts of dry matter fed. This was because the high

group resulted in higher yields of fat, protein, and mature equivalent (ME) milk compared to the low group, even though the high group had higher costs from a higher feed consumption (Vibart et al., 2012). Marston et al. (2011) found that cows who were fed grass silage with commodity concentrates had lower feed costs and higher IOFC compared to other rations, and a corn silage and commodity concentrate diet had the highest observed feed costs. Grasser (1995) found that commodity by-products that have high availability within a region are likely viable options and should be used on dairies due to their low costs. Milligan and Knoblauch (1980) considered forage quality, finding higher quality hay crops, or those forages with higher nutritional content, important for controlling feed costs.

Although IOFC is an effective tool to measure the short-term impact on a dairy's bottom line, it fails to consider long-term effects of nutrition on resiliency. Previous studies do not evaluate the effect of nutrition and other herd management characteristics on whole-farm profitability over the long term. Hadrich and Johnson (2015) performed a study on the effect of risk management practices on revenue and purchased feed costs. This was analyzed across eight states using data from 2010 and considered nutrition factors, including whether or not a nutritionist was used, and the percentage of homegrown forages utilized (Hadrich and Johnson, 2015). In Minnesota, using a nutritionist increased purchased feed costs and feeding homegrown forage decreased purchased feed costs (Hadrich and Johnson, 2015). This study, however, was limited to one year of data and did not analyze whole-farm profitability, although it analyzed nutrition-specific questions with revenue and feed cost analysis. Krpálková et al. (2014) studied the effects of age at first calving, heifer average daily gain, herd milk yield and

production, and reproduction on profitability. This directly tied to heifer nutrition impacting profitability through analysis of average daily gain (Krpálková et al., 2014). It did not consider other financial indicators in the analysis and only considered profitability over a one-year period in 2011 (Krpálková et al., 2014).

Research has been performed on maximizing milk production and minimizing feed costs through ration formulation. Research has also been performed on nutrition's impact on revenue, short-term profitability, and IOFC. However, no research exists on the impact of the feeding decision on long-term whole-farm profitability, including both cow health and financial characteristics. The objective of this study is to combine the science of nutrition and production with financial performance to determine the implications of cow nutrition on Minnesota dairy farm resiliency.

Chapter 4

Data

Data was compiled from two sources: the Minnesota Dairy Herd Improvement Association (DHIA; Buffalo, MN) and the University of Minnesota Center for Farm Financial Management's online database (FINBIN; St. Paul, MN). Data from the Minnesota DHIA provides dairy farm management measurements, including cow-level production information for each herd tested. The DHIA data included the cows' identification numbers, lactation number, milk yield, milk fat level, milk protein level, test dates, days in milk (DIM), calving dates, culling information, and more as they relate to cow-level production characteristics. Data from FINBIN, which provides detailed reports of farm finances, included farm-level financial information as well as detailed herd-level feedstuff quantities and expenses. Only farms that participated in FINBIN and were tested by DHIA were included in the dataset. Data from both the Minnesota DHIA and FINBIN were collected from 2012 to 2018. These years were used as they reflect the fluctuating market conditions of the dairy industry with relatively high milk prices in 2014 and relatively low milk prices in 2018. The DHIA data was imported to Stata (Stata Statistical Software: Release 16; StataCorp, College Station, TX) by cow lactation number, whereas FINBIN data was imported based on the year the finances accrued. Because the lactation data could follow through more than one year, DHIA data had to be converted from a lactation basis to an annual basis to match FINBIN data. This was done by splitting each lactation into separate years based on the number of days each cow stayed in the herd within a calendar year. This allowed annual finances to be matched to

time specific cow lactation performance across the calendar year. Converting the production data from a cow's lactation to a calendar year is crucial to mirror the finances each cow incurs on the farm, which determines farm-level resiliency. Important variables, such as milk yield, fat yield, protein yield, DIM, and somatic cell score (SCS) were all converted to a calendar year to accurately portray the finances for each cow.

The DHIA data for each lactation was split into years to smoothly transition the data from a lactation basis to an annual basis. Because lactations could span into two different years depending on when the cow calved and whether or not she was culled, the number of days she remained in the herd for each year was calculated for each lactation. For example, if a cow calved on December 1, 2013, the cow would be included in two years. For the 2013 lactation, the cow would be in the data for 30 days, while in 2014, the cow's lactation days include the time in the herd through her dry period if she is not culled, or for the number of days she remains in the herd from January 1, 2014 if she is culled. Production data, as well as other cow characteristics, like lactation number, were allocated by year following the number of days a cow remained in the herd in each year. The lactation data was then transformed from a wide format to a long format, giving each cow a separate entry for each year she was in the herd rather than being separated by lactation.

Once the data was converted to a long format, several adjustments were made to accurately represent the lactation data on an annual basis. Calf data, including the sex of the calf and twinning data, were only included for cows that began their lactation within that year. Each cow received an average dry period of 60 days at the end of her lactation if she was not culled. The number of days a cow remained in the herd (days in the herd)

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was calculated as her DIM plus the number of days she was dry. Days in the herd, DIM, and days dry were updated if a second calving date was available for the cow within a year for her second lactation within that year. This was completed to ensure days did not exceed 365 days per year (or 366 days for leap years). Production values, including milk, fat, and protein yield were adjusted to new levels if the DIM were inaccurate previously by multiplying the old daily values by the new DIM. After converting DHIA data to an annual basis, financial data was merged in at the herd-level, matching the same calendar year as the DHIA data. Herds with incomplete data were dropped.

4.1   Non-Feed Expense Allocation

The FINBIN herd-level expenses were merged into the dataset and converted to a cow level to match the cow-level production data from DHIA. Using a similar method to Roberts (2019), expenses were allocated using two methods – an equal weighting (EW) method and a production group weighting (PGW) method. The EW method allocated equal expenses to each cow, regardless of her milk production, giving each cow within each herd the same daily expense. The PGW method differed from the EW method by allocating herd expenses to each cow based on if she produced in the high energy corrected milk (ECM)[2] group or the average ECM group. The mean ECM was calculated for each herd each year to create the two groups. The high ECM group consisted of cows

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[2] ECM is calculated using a formula from Dairy Records Management Systems' DHI Glossary (2014) such that,
$$ECM = (0.327 * MilkYield) + (12.95 * FatYield) + (7.65 * ProteinYield)$$
where *ECM* is Energy Corrected Milk in pounds, *MilkYield* is pounds of milk produced, *FatYield* is pounds of milk fat produced, and *ProteinYield* is pounds of milk protein produced.

who produced an ECM of 110% or higher compared to herdmates, while cows that had an ECM level of less than 110% of herdmates were in the average ECM group. All expenses with the exception of feed expenses were allocated for the PGW dataset based on this method created by Roberts (2019). After merging the datasets and creating the cow-level expenses, the detailed feed data from FINBIN was able to be allocated to the cow level.

4.2   Feed Allocation

Feed data was obtained from FINBIN and consisted of annual feedstuffs fed at the herd-level from 2012 to 2018. Feed variables for this data included total feed quantities in pounds and total feed expenses in dollars for 63 different feedstuffs for each farm and year. Feed expenses in this data included the purchase cost if the feed was purchased and the market value if the feed was homegrown. The data was imported from Microsoft Excel into Stata and merged into the expense allocated datasets by FINBIN identification number and year of the observations.

Feed quantities and expenses were allocated from a farm level to a cow level three ways to determine the most accurate way annual feed should be allocated to a cow level. These three methods for feed allocation include equal weighting (EW), production group weighting (PGW), and volume weighting (VW). These three feed allocation methods are based on those originally created by Roberts (2019).

4.2.1   Equal Weighting (EW) Feed Allocation

The first method used to allocate feed consumption to each cow was done using an EW allocation. Each cow received the same quantity and expense of feed per day, regardless of milk production and whether she was milking or dry. The daily value was multiplied by the number of days the cow remained in the herd, such that,

(1) $Q\_feed_{fnit}^{EW} = \frac{Q_{totalfeed_{fit}}}{\sum_{n=1}^{N} daysinherd_{nit}} * daysinherd_{nit}$

(2) $E\_feed_{fnit}^{EW} = \frac{E_{totalfeed_{fit}}}{\sum_{n=1}^{N} daysinherd_{nit}} * daysinherd_{nit}$

where $Q\_feed_{fnit}^{EW}$ is the *EW* quantity of each feedstuff *f* for the *n*th cow in the *i*th herd for year *t*, $Q_{totalfeed_{fit}}$ is the total quantity of each feedstuff *f* for the *i*th herd for year *t*, $daysinherd_{nit}$ is the total number of days the *n*th cow is in the *i*th herd for year *t* (= 365 or 366 days if not culled, < 365 or 366 days if culled), $E\_feed_{fnit}^{EW}$ is the *EW* expense of each feedstuff *f* for the *n*th cow in the *i*th herd for year *t*, and $E_{totalfeed_{fit}}$ is the total expense of each feedstuff *f* for the *i*th herd for year *t*. All variables created for the quantity and expense allocations will use "Q_" and "E_" to represent the difference between the continuous quantities of feedstuffs (Q) and the continuous expenses of feedstuffs (E).

4.2.2   *Production Group Weighting (PGW) Feed Allocation*

The PGW feed allocation differed slightly from the PGW expense allocation designed by Roberts (2019). Cows that produce more milk require a greater DMI, as these cows are converting greater amounts of nutrients into higher milk yield (Bach et al., 2020). Because of this, the feed consumption was specifically allocated based on high-

producing cows consuming more feed, thus incurring higher feed costs.[3] The PGW

method allocated annual feed data to cows based on ECM production categorized in a

high or average production group. This feed allocation method was added to the PGW

expense dataset. Similar to the PGW expense method, cows that had ECM of 110% or

higher compared to herdmates received an "A" ranking for the high production group,

while cows that had an ECM level of less than 110% of herdmates received a "B"

ranking for the average production group. According to Penn State University Extension,

high-producing cows have a DMI of 4.0% or more of their bodyweight, whereas low-

producing cows have a DMI of 3.0% or more of their bodyweight (Heinrichs and

Kmicikewycz, 2016). Assuming the cows in both groups have the same bodyweight, the

ratio of 4:3 was used for feed consumption differences. Because cows that produce more

milk consume more feed, feed was allocated to cows based on the high production group

consuming 33% more feed per day than the low production group. Feed was allocated in

this way based on the number of days in the herd, regardless of the number of days she

was milking versus dry. Total annual feed quantities and expenses for each high cow and

average cow were allocated, such that,

$$(3) \ Q\_feed_{fnit}^{PGW_B} = \frac{Q_{totalfeed_{fit}}}{(\sum_{n=1}^{N} daysinherd_{nit}^{B}) + ((\sum_{n=1}^{N} daysinherd_{nit}^{A}) * 1.33)} * daysinherd_{nit}^{B}$$

$$(4) \ Q\_feed_{fnit}^{PGW_A} = \frac{Q_{totalfeed_{fit}}}{((\sum_{n=1}^{N} daysinherd_{nit}^{B})/1.33) + (\sum_{n=1}^{N} daysinherd_{nit}^{A})} * daysinherd_{nit}^{A}$$

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[3] The cow-level expense value that was originally calculated in the PGW expense dataset did not include feed expense, as this was subtracted out of the original total herd-level expense. After allocating the feed consumption quantities and expenses to the cow level based on this PGW method, a new value was generated for the annual cow-level expenses by adding together the cow-level expense without the feed expense with the newly created cow-level feed expense.

$$(5) \ E\_feed_{fnit}^{PGW_B} = \frac{E_{totalfeed_{fit}}}{(\sum_{n=1}^{N} daysinherd_{nit}^{B}) + ((\sum_{n=1}^{N} daysinherd_{nit}^{A}) * 1.33)} * daysinherd_{nit}^{B}$$

$$(6) \ E\_feed_{fnit}^{PGW_A} = \frac{Q_{totalfeed_{fit}}}{((\sum_{n=1}^{N} daysinherd_{nit}^{B})/1.33) + (\sum_{n=1}^{N} daysinherd_{nit}^{A})} * daysinherd_{nit}^{A}$$

where $Q\_feed_{fnit}^{PGW_B}$ is the PGW quantity of each feedstuff f for the nth B cow in the ith herd for year t, $Q_{totalfeed_{fit}}$ is the total quantity of each feedstuff f for the ith herd for year t, $daysinherd_{nit}^{B}$ is the total number of days the nth B cow remains in herd i during year t (= 365 or 366 days if not culled, < 365 or 366 days if culled), $daysinherd_{nit}^{A}$ is the total number of days the nth A cow remains in herd i during year t (= 365 or 366 days if not culled, < 365 or 366 days if culled), $Q\_feed_{fnit}^{PGW_A}$ is the PGW quantity of each feedstuff f for the nth A cow in the ith herd for year t, $E\_feed_{fnit}^{PGW_B}$ is the PGW expense of each feedstuff f for the nth B cow in the ith herd for year t, $E_{totalfeed_{fit}}$ is the total expense of each feedstuff f for the ith herd for year t, and $E\_feed_{fnit}^{PGW_A}$ is the PGW expense of each feedstuff f for the nth A cow in the ith herd for year t. Allocating the feed in this way allows for greater variation in the dataset and potentially greater accuracy for how much feed is actually consumed by cows.

The PGW feed allocation method is shown in detail in Figure 1. In this example, Farm 1 feeds 3 million pounds of corn silage in 2012 to 430 cows. Of the 430 cows, 180 cows have an ECM 110% or higher of their herdmates and are considered part of the "A" group, or high production group. Two hundred fifty cows have an ECM lower than 110% of their herdmates, receiving a "B" ranking as part of the average production group. Because the high production group is expected to consume 33% more feed per day than

the average production group, the total number of equivalent days for each group is calculated. For example, the total number of "B" cow days in the herd of 80,000 is divided by 1.33 to find the total number of days equivalent to "A" cows if "B" cows had the same feed consumption. The same is done to the "A" cow days, instead multiplying the total number of days in the herd for "A" cows of 60,000 by 1.33 (the feed consumption ratio) to get the total number of days in the herd equivalent to "B" cows if both groups had the same feed consumption. Next, the daily intake for each production group was calculated by dividing the total pounds of corn silage consumed by all cows by the total number of days in the herd if both groups consumed the same amount of feed each day. This resulted in 24.97 pounds of corn silage consumed per cow per day for the high production group and 18.77 pounds of corn silage consumed per cow per day for the average production group. Finally, this daily intake was translated to a yearly intake for each cow by multiplying the daily intake by the days in the herd for each cow, giving each cow their own value of corn silage intake for 2012. The feed was allocated in this way for quantities of each feedstuff (Figure 1) and the expenses of each feedstuff.

Production Group Weighting Feed Allocation

2012 Corn Silage Consumption for 430 cows on Farm 1:
3,000,000 lbs.

"A" cows
(High Production)

"B" cows
(Average Production)

High production cows on Farm 1:
180 cows

$$^{2012}_{t}\Sigma \text{ Days in Lactation}^{High}_{t}$$

Average production cows on Farm 1:
250 cows

$$^{2012}_{t}\Sigma \text{ Days in Lactation}^{Avg}_{t}$$

Total Days in the herd for 180 "A" cows:
60,000 days

Total Days in the herd for 250 "B" cows:
80,000 days

Total "B" Cow Days / 1.33 = Equivalent number of "A" cow days

"A" cows consume 33% more feed than "B" cows

Total "A" Cow Days * 1.33 = Equivalent number of "B" cow days

"A" cows consume 33% more feed than "B" cows

"B" cow days equivalent to "A" cow days if they had the same daily intake:
60,150 days

"A" cow days equivalent to "B" cow days if they had the same daily intake:
79,800 days

Total 2012 Corn Silage Consumption / (Equivalent number of n cow days + Total n cow days) = Daily Corn Silage Intake for n Cows

Daily Corn Silage Intake for "A" cows:
24.97 lbs./day

Daily Corn Silage Intake for "B" cows:
18.77 lbs./day

Daily Corn Silage Intake per Cow * Days in Milk = Total 2012 Corn Silage Intake per Cow

"A" Cow ID #2 in the herd
365 days

"B" Cow ID #5 in the herd
289 days

Total 2012 Corn Silage Intake for Cow ID #2:
9,113.58 lbs.

Total 2012 Corn Silage Intake for Cow ID #5:
5,424.53 lbs.

Figure 1: A Flow Chart Example of the PGW Feed Allocation Method.

4.2.3 Volume Weighting (VW) Feed Allocation

Cows consume different levels of feed based on their specific energy requirements. Cows that produce more milk need to consume more energy, resulting in higher DMI (Bach et al., 2020). This creates unique challenges when allocating herd-level annual feed quantities and expenses to a cow level. Assigning a DMI based on cows' milk production was considered, but no simplistic way of reconciling the annual feed quantities and daily feed requirements tied to milk production exists. The NRC (2001) reports two methods for calculating DMI, but neither were feasible considering our data.[4] To ensure the feed consumption follows ECM produced by each cow while also adding up to the reported amounts in FINBIN, a proportional feed allocation was used based on the volume of ECM for each cow within the herd each year.[5]

A standard measure was used to allocate feed quantities and expenses during the dry period, giving all cows who reached the dry period the same daily feed values during

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[4] The NRC (2001) reports two formulas for calculating DMI from nutrition and production information; however, neither are feasible given the data in this study. The first formula would require net energy of lactation (NEL) from the feed data, which would cause large assumptions due to the lack of quality analysis for the feedstuffs in this study. This formula calculates DMI using NEL, such that,

$$DMI\ (kg) = \frac{NEL\ required\ (Mcal)}{NEL\ concentration\ of\ diet\ (\frac{Mcal}{kg})}$$

where *DMI* is the dry matter intake for each cow in kilograms, *NEL required* is the net energy of lactation required by the dairy cow in megacalories, and *NEL concentration of diet* is the concentration of net energy of lactation from the diet found in the feedstuffs in megacalories per kilogram. The second formula reported by the NRC (2001) would calculate the weekly DMI for each cow, which would be too detailed considering the annual feed data used in this study. Weekly body weights as well as daily fat corrected milk would be needed for this formula. This formula calculates DMI, such that,

$$DMI\ \left(\frac{kg}{d}\right) = (0.372 * FCM + 0.0968 * BW^{0.75}) * \left(1 - e^{(-0.192*(WOL+3.67))}\right)$$

where *DMI* is the dry matter intake for each cow each day in kilograms per day, *FCM* is 4 percent fat corrected milk measured in kilograms per day, *BW* is the weekly body weight in kilograms, and *WOL* is the week of lactation.

[5] The VW calculation for this analysis differs from Roberts (2019) to capture an individual feed allocation while keeping all expenses based on the PGW method besides feed expenses.

that period. For the EW and PGW feed allocation methods, the dry period received the

same daily feed consumption values as the cow did while lactating. This was not used for

the VW feed allocation. The NRC (2001) reports that the average dry cow approximately

240 days pregnant has a DMI of 31.7 pounds per day. Using the DHIA reported milk

yield, the average daily milk production for each cow in the dataset is 73.1 pounds per

cow per day. This average daily milk production falls within two reported values from

the NRC (2001). According to the NRC (2001), an average Holstein cow producing 55

pounds of milk per day has a DMI of 44.7 pounds per day, while an average Holstein

cow producing 77 pounds of milk per day has a DMI of 51.9 pounds per day.

Considering the same proportion of milk production to DMI, the average cow in the

dataset producing 73.1 pounds of milk per day consumes a DMI of approximately 50.6

pounds per day.

The value of 50.6 pounds of average daily DMI for a lactating cow in the dataset

was compared with the NRC value of 31.7 pounds of average daily DMI for a dry cow.

These numbers showed that the average lactating cow in our dataset consumes 60% more

feed than the average dry cow. Feed quantities and expenses for cows during the dry

period were allocated, such that,

$$(7) \quad Q\_feed_{fnit}^{VW_{dry}} = \frac{Q_{totalfeed_{fit}}}{\left(\sum_{n=1}^{N} daysdry_{nit}\right)+\left(\left(\sum_{n=1}^{N} DIM_{nit}\right)*1.60\right)} * daysdry_{nit}$$

$$(8) \quad E\_feed_{fnit}^{VW_{dry}} = \frac{E_{totalfeed_{fit}}}{\left(\sum_{n=1}^{N} daysdry_{nit}\right)+\left(\left(\sum_{n=1}^{N} DIM_{nit}\right)*1.60\right)} * daysdry_{nit}$$

where $Q\_feed_{fnit}^{VW_{dry}}$ is the *VW* quantity of each feedstuff *f* for the *n*th *dry* cow in the *i*th

herd for year *t,* $Q\_totalfeed_{fit}$ is the total quantity of each feedstuff *f* for the *i*th herd for

year *t*, $daysdry_{nit}$ is the number of days the *n*th cow is dry in the *i*th herd for year *t*,

DIM_{nit} is the number of days the *n*th cow is lactating in the *i*th herd for year *t*,

$E\_feed_{fnit}^{VW_{dry}}$ is the *VW* expense of each feedstuff *f* for the *n*th *dry* cow in the *i*th herd for

year *t*, and $E\_totalfeed_{fit}$ is the total expense of each feedstuff *f* for the *i*th herd for year

t.

       Dry period feed quantities and expenses were subtracted from the total herd feed

quantities and expenses. The remaining feed was allocated to the lactating cows using a

proportional allocation of ECM. Approximately 3,215 observations for ECM were

missing for cows in the dataset.[6] The DIM for these cows ranged from 1 to 360 days,

with a median of 30 days and mean of 64.4 days. A large majority of missing

observations for ECM was likely due to health issues during the transition period due to

the low median and mean number of DIM for the cows missing ECM information. ECM

values were adjusted for missing observations since these cows still consumed feed, even

though they were missing test data. ECM for cows missing test data was calculated as the

daily herd average ECM for each year multiplied by the number of DIM for that year.[7]

The adjusted ECM values were only used for the feed allocation; they were not used for

any other analysis in this study since they were assumed values. This allowed cows who

did not have ECM values to still be allocated feed quantities and expenses to make the

rest of the cows in the dataset have a more accurate representation of feed consumption.

Including the adjusted ECM values for missing observations, feed quantities and

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[6] Approximately 3,215 observations had a missing value for ECM out of 88,958 observations where DIM
was not equal to missing and greater than zero.
[7] Daily herd average ECM was calculated as the mean ECM taken across all cows for each farm each year.

expenses for the lactating herd were then allocated as a percentage of the herd ECM, such that,

$$(9) \qquad Q\_feed_{fnit}^{VW\ milk} = (\frac{ECM_{nit}}{HerdECM_{it}}) * Q\_totalfeed_{fit}^{milk}$$

$$(10) \qquad E\_feed_{fnit}^{VW\ milk} = (\frac{ECM_{nit}}{HerdECM_{it}}) * E\_totalfeed_{fit}^{milk}$$

where $Q\_feed_{fnit}^{VW\ milk}$ is the VW quantity of each feedstuff f for the nth lactating cow in the ith herd for year t, ECM_{nit} is the energy corrected milk produced by the nth cow in the ith herd for year t, $herdECM_{it}$ is the total energy corrected milk produced by the ith herd for year t, $Q\_totalfeed_{fit}^{milk}$ is the total quantity of each feedstuff f for lactating cows in the ith herd for year t, $E\_feed_{fnit}^{VW\ milk}$ is the VW expense of each feedstuff f for the nth lactating cow in the ith herd for year t, and $E\_totalfeed_{fit}^{milk}$ is the total expense of each feedstuff f for lactating cows in the ith herd for year t.

Finally, the yearly lactating and dry period feed quantities and expenses were added together for each cow. Additionally, as done in the PGW method, a new value was generated for the annual cow-level expenses by adding together the cow-level expense without the feed expense with the newly created cow-level feed expense.

Allocating the feed individually to cows in the dataset ensures greater variation and accuracy in the data. However, several assumptions had to be made for the level of ECM produced and for the feed consumption during the dry period when allocating the feed in this manner.[8]

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[8] Assumptions for the VW feed allocation method include: (1) feed being allocated based on the proportion of ECM produced compared to the whole herd, (2) the dry period being a strict 60 days per cow if she was not culled in that lactation, and (3) cows consuming 60% less feed daily during the dry period when compared to daily feed consumption while lactating.

4.2.4 Feed Data Outliers

Daily feed quantities and expenses were validated against industry averages (NRC, 2001; FINBIN, 2020) to identify outliers. Using the DHIA reported milk yield, the average daily milk production for each cow in the dataset was 73.1 pounds per cow per day. As discussed above in the *Volume Weighting Feed Allocation* section, using proportions from the NRC (2001), the average cow in the dataset is expected to consume a DMI of 50.6 pounds per day. Daily feed quantities calculated from the feed allocation methods were checked against this average daily DMI. In addition, FINBIN (2020) reported that the average yearly feed cost per cow in Minnesota was $2,015.16 in 2019. This can be converted to a daily level by dividing the feed cost per cow by 365 days, resulting in an average daily feed cost of $5.52 per cow.

If daily feed quantity or expense observations were two or more standard deviations from the mean or within the top or bottom 1% of observations comparative to the industry averages reported by the NRC (2001) or FINBIN (2020), observations were set to missing. Appendix A demonstrates when each of these rules were used for each feedstuff. Values that were too high or too low for a cow's daily consumption were likely due to the feed allocation methods, so outliers were identified and set to missing. Values that were unrealistically high or low were identified by considering dry matter percentage from the NRC (2001) and daily feed expenses as each feed variable is one portion of a cow's ration. All feed expense observations that had a value reported as zero while the quantity fed was greater than zero were replaced with the average feed cost for that feedstuff for farms that reported it in the dataset. This was done to allow observations that had feed quantities reported to still have an expense associated with those feeds. A

quantity value of zero indicated the feedstuff was not fed on the farm. All feedstuffs not

fed by a farm were reported with zeros to accurately represent the amount of feedstuff fed

on that farm.

Chapter 5

Methodology

5.1   Step 1 – Cow Nutrition's Impact on Energy Corrected Milk

5.1.1   Feed Data Setup

The first step of analyzing the feeding decision's impact on dairy farm resiliency

was to assess which feeds have a significant impact on milk production. FINBIN has a

list of 63 feeds available for reporting by producers. Of these feeds, corn silage, corn,

"protein, vitamins, and minerals", and alfalfa hay were the most commonly reported

while a number of feeds were not used at all (Appendix B). A number of feed options

were combined to generate composite feedstuffs. Corn silage and sweet corn silage were

combined into one variable called "all corn silage" ($Q\_allCornSilage$; Equation 11), and

corn and ear corn were combined into one called "all corn" ($Q\_allCorn$; Equation 12). A

composite hay variable was created, which combined alfalfa hay, grass hay, mixed hay,

hay, and small grain hay into one called "all hay" (Q_allHay; Equation 13). Additionally,

"protein, vitamins, and minerals", "complete ration", and protein supplements were

combined into one variable termed "all protein, vitamins, and minerals" (Q_PVM_I;

Equation 14). A composite variable termed "all DDGS" ($Q\_allDDGS$; Equation 15) was

created that combined both wet and dry distillers grains (DDGS) along with corn gluten

because of its similar properties to DDGS. These composite variables were calculated,

such that,

(11) $Q\_allCornSilage_{nit} = Q\_CornSilage_{nit} + Q\_SweetCornSilage_{nit}$

(12) $Q\_allCorn_{nit} = Q\_Corn_{nit} + Q\_EarCorn_{nit}$

30

(13) $Q\_allHay_{nit} = Q\_AlfalfaHay_{nit} + Q\_GrassHay_{nit} +$

  $Q\_MixedHay_{nit} + Q\_Hay_{nit} + Q\_SmallGrainHay_{nit}$

(14) $Q\_PVM\_I_{nit} = Q\_ProtVitMin_{nit} + Q\_CompleteRation_{nit} +$

  $Q\_ProteinSupplement_{nit}$

(15) $Q\_allDDGS_{nit} = Q\_DDGSwet_{nit} + Q\_DDGSdry_{nit} + Q\_CornGluten_{nit}$

where $Q\_allCornSilage_{nit}$ is the quantity consumed of corn silage and sweet corn silage

by the nth cow in the ith herd for year t, $Q\_CornSilage_{nit}$ is the quantity consumed of

corn silage by the nth cow in the ith herd for year t, $Q\_SweetCornSilage_{nit}$ is the

quantity consumed of sweet corn silage by the nth cow in the ith herd for year t,

$Q\_allCorn_{nit}$ is the quantity consumed of corn and ear corn by the nth cow in the ith

herd for year t, Q_Corn_{nit} is the quantity consumed of corn by the nth cow in the ith herd

for year t, $Q\_EarCorn_{nit}$ is the quantity consumed of ear corn by the nth cow in the ith

herd for year t, Q_allHay_{nit} is the quantity consumed of all hay types (alfalfa hay, grass

hay, mixed alfalfa/grass hay, "hay", and small grain hay) by the nth cow in the ith herd

for year t, $Q\_AlfalfaHay_{nit}$ is the quantity consumed of alfalfa hay by the nth cow in

the ith herd for year t, $Q\_GrassHay_{nit}$ is the quantity consumed of grass hay by the nth

cow in the ith herd for year t, $Q\_MixedHay_{nit}$ is the quantity consumed of mixed

alfalfa/grass hay by the nth cow in the ith herd for year t, Q_Hay_{nit} is the quantity

consumed of "hay" (as reported in FINBIN as simply "hay") by the nth cow in the ith

herd for year t, $Q\_SmallGrainHay_{nit}$ is the quantity consumed of small grain hay by the

nth cow in the ith herd for year t, $Q\_PVM\_I_{nit}$ is the quantity consumed of "protein,

vitamins, and minerals", "complete ration", and protein supplements by the nth cow in

the ith herd for year t, $Q\_ProtVitMin_{nit}$ is the quantity consumed of feed recorded as "proteins, vitamins, and minerals" in FINBIN by the nth cow in the ith herd for year t, $Q\_CompleteRation_{nit}$ is the quantity consumed of feeds reported as "complete ration" in FINBIN by the nth cow in the ith herd for year t, $Q\_ProteinSupplement_{nit}$ is the quantity consumed of protein supplement by the nth cow in the ith herd for year t, $Q\_allDDGS_{nit}$ is the quantity consumed of dried distillers grains, wet distillers grains, and corn gluten by the nth cow in the ith herd for year t, $Q\_DDGSwet_{nit}$ is the quantity consumed of wet distillers grains by the nth cow in the ith herd for year t, $Q\_DDGSdry_{nit}$ is the quantity consumed of dried distillers grains by the nth cow in the ith herd for year t, and $Q\_CornGluten_{nit}$ is the quantity consumed of corn gluten feed by the nth cow in the ith herd for year t. All of these composite variables shown in equations 11-15 were calculated for continuous quantities, as well as continuous expenses of feedstuffs.[9]

A percent roughage variable was created that calculated the percentage of the ration that was roughage (e.g. hay, haylage, silage, pasture, etc.), rather than concentrate. For the percent roughage variable to be calculated, each feed was converted from an as fed basis to a dry matter basis, using the NRC's (2001) nutrient evaluations of feeds. For feeds reported in FINBIN that were not found in the NRC (2001), assumptions were made for dry matter content based on the feeds' characteristics and insights from professional nutritionists. "Protein, vitamins, and minerals" and "complete ration" were assumed to be approximately 95% dry matter, based on the feeds being included in these

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[9] As stated earlier in the *Equal Weighting Feed Allocation* section, continuous quantities of feedstuffs are represented by "Q_", while continuous expenses of feedstuffs are represented by "E_". The formulas used in equations 11-15 were also performed for continuous expenses for the same feedstuff variables starting with "E_".

categories being relatively dry feeds. In addition, protein supplement was assumed to be approximately 90% dry matter, based on assessing various dairy cattle protein supplements. Once the dry matter calculations were made, percent roughage was calculated, such that,

$$(16) \quad PercentRoughage_{nit} = ((Q\_CornSilageDM_{nit} +$$

$$Q\_AlfalfaHayDM_{nit} + Q\_GrassHayDM_{nit} + Q\_MixedHayDM_{nit} +$$

$$Q\_PastureDM_{nit} + Q\_SmGrainHayDM_{nit} + Q\_AlfHaylageDM_{nit} +$$

$$Q\_GrassHaylageDM_{nit} + Q\_MixedHaylageDM_{nit} + Q\_OatlageDM_{nit} +$$

$$Q\_RyeSilageDM_{nit} + Q\_SorgSilageDM_{nit} + Q\_BarlSilageDM_{nit} +$$

$$Q\_SwtCornSilDM_{nit} + Q\_BaleageDM_{nit} + Q\_SnaplageDM_{nit} +$$

$$Q\_HayDM_{nit})/ (Q\_TotalFeedDM_{nit})) * 100$$

where $PercentRoughage_{nit}$ is the percent roughage of dietary dry matter (DM) consumed by the nth cow in the ith herd for year t, $Q\_CornSilageDM_{nit}$ is the quantity of DM consumed of corn silage by the nth cow in the ith herd for year t, $Q\_AlfalfaHayDM_{nit}$ is the quantity of DM consumed of alfalfa hay by the nth cow in the ith herd for year t, $Q\_GrassHayDM_{nit}$ is the quantity of DM consumed of grass hay by the nth cow in the ith herd for year t, $Q\_MixedHayDM_{nit}$ is the quantity of DM consumed of mixed alfalfa/grass hay by the nth cow in the ith herd for year t, $Q\_PastureDM_{nit}$ is the quantity of DM consumed of pasture by the nth cow in the ith herd for year t, $Q\_SmGrainHayDM_{nit}$ is the quantity of DM consumed of small grain hay by the nth cow in the ith herd for year t, $Q\_AlfHaylageDM_{nit}$ is the quantity of DM consumed of alfalfa haylage by the nth cow in the ith herd for year t,

$Q\_GrassHaylageDM_{nit}$ is the quantity of DM consumed of grass haylage by the *n*th

cow in the *i*th herd for year *t*, $Q\_MixedHaylageDM_{nit}$ is the quantity of DM consumed

of mixed alfalfa/grass haylage by the *n*th cow in the *i*th herd for year *t*, $Q\_OatlageDM_{nit}$

is the quantity of DM consumed of oatlage by the *n*th cow in the *i*th herd for year *t*,

$Q\_RyeSilageDM_{nit}$ is the quantity of DM consumed of rye silage by the *n*th cow in the

*i*th herd for year *t*, $Q\_SorgSilageDM_{nit}$ is the quantity of DM consumed of sorghum

silage by the *n*th cow in the *i*th herd for year *t*, $Q\_BarlSilageDM_{nit}$ is the quantity of

DM consumed of barley silage by the *n*th cow in the *i*th herd for year *t*,

$Q\_SwtCornSilDM_{nit}$ is the quantity of DM consumed of sweet corn silage by the *n*th

cow in the *i*th herd for year *t*, $Q\_BaleageDM_{nit}$ is the quantity of DM consumed of

baleage hay by the *n*th cow in the *i*th herd for year *t*, $Q\_SnaplageDM_{nit}$ is the quantity of

DM consumed of corn snaplage by the *n*th cow in the *i*th herd for year *t*, Q_HayDM_{nit} is

the quantity of DM consumed of "hay" by the *n*th cow in the *i*th herd for year *t*, and

$Q\_TotalFeedDM_{nit}$ is the quantity of DM consumed of all feed by the *n*th cow in the *i*th

herd for year *t*.

A dummy variable, $PercentRoughageRange_{nit}$, was created in addition to this

continuous variable. The optimal percentage of roughage in the diet is between 40-60%

of ration DM (NRC, 2001). The dummy variable for percent roughage was equal to one if

the percent roughage fell within the optimal range and equal to zero if the percent

roughage was outside the range.

5.1.2   ECM Regression Setup

Milk production, measured by ECM, was estimated using fixed-effects

regressions. A fixed-effects model is used to control for time-invariant unobserved cow

characteristics to measure the effect of the observed explanatory variables over time

(StataCorp, 2019). StataCorp (2019) states that the fixed-effects estimator uses OLS to

perform the estimation of

(17) $\qquad (y_{it} - \bar{y}_i) = \alpha + (x_{it} - \bar{x}_i)\beta + (\varepsilon_{it} + \bar{\varepsilon}_i),$

where y_{it} is the dependent variable measured for the ith entity for time period t, $\bar{y}_i$ is the

average of the dependent variable measured for the ith entity across all time periods, x_{it}

is the explanatory variable measured for the ith entity for time period t, $\bar{x}_i$ is the average

of the explanatory variable measured for the ith entity across all time periods, β is the

coefficient on the explanatory variable, and $(\varepsilon_{it} + \bar{\varepsilon}_i)$ is the error term.

A Hausman test was performed to ensure the data fit the fixed-effects model best.

ECM was used as the measure of milk production to consider milk fat and protein yield

jointly with milk yield. Using the fixed-effects model, farm, cow, and year are controlled

for to measure the effect of feedstuff consumption and other cow characteristics on ECM

at a cow level across time.

Explanatory variables used in this analysis included continuous and binary

variables for quantities of feedstuffs. Binary feed variables were used for feeds with

fewer observations (less than 70,000 observations). The average somatic cell score (SCS)

across a cow's lactations for a single year and dummy variables for second lactation and

third and higher lactations were added to the regressions to control for differences due to

udder health (SCS) and maturity (lactations). A cow may experience two lactations

within one calendar year or one lactation over multiple calendar years. For this analysis, a cow's annual lactation number was identified by having eight or more months of a calendar year dedicated to that lactation, while considering the dry period as part of the previous lactation. If the first lactation observed in that year lasted eight months or more, she was designated that specific lactation. If the first lactation observed in that year lasted less than eight months, the second lactation observed in that year was considered the cow's annual lactation number. This is because a cow is more likely to hit her peak milk production in the first 90 to 120 days, or three to four months, of her lactation. In her second lactation that year, she is producing more milk than she would in the previous lactation. For example, in calendar year 2013, a cow may be lactating for nine months in her first lactation, dry for two months, and lactate for one month in her second lactation. In 2013, this cow was designated as a first lactation cow.

Three regressions were used to show how feeds from FINBIN affect yearly ECM for each feed allocation method. The difference in the three regressions is the level of detail of binary feedstuffs. As binary feedstuffs are taken out of each regression, a new variable is created for protein, vitamins, and minerals, which combines the continuous quantity of "all protein, vitamins, and minerals" (Q_PVM_I; Equation 14) with the continuous quantities of feedstuffs removed from the regressions. These variables are called $Q\_PVM\_II_{nit}$ for ECM Regression II and $Q\_PVM\_III_{nit}$ for ECM Regression III.

In the first regression, ECM Regression I, each feedstuff was included individually as reported in FINBIN along with the dummy variable for the percentage of roughage being in the range of 40-60% of ration DM. ECM Regression I (Equation 18)

has the highest level of detail, which may help explain the impact of individual feedstuffs on ECM more accurately, such that,

$$(18) \quad ECM_{nit} = \beta_0 + \beta_1 SCS_{nit} + \beta_2 lact2_{nit} + \beta_3 lact3_{nit} + \beta_4 Q\_PVM\_I_{nit} +$$

$$\beta_5 Q\_allCorn_{nit} + \beta_6 Q\_allCornSilage_{nit} + \beta_7 Q\_allHay_{nit} +$$

$$\beta_8 Cottonseed_{nit} + \beta_9 BeetPulp_{nit} + \beta_{10} Oats_{nit} + \beta_{11} Pasture_{nit} +$$

$$\beta_{12} allDDGS_{nit} + \beta_{13} Barley_{nit} + \beta_{14} Soybeans_{nit} +$$

$$\beta_{15} PercentRoughageRange_{nit} + \varepsilon_{nit}$$

where ECM_{nit} is the energy corrected milk produced by the nth cow in the ith herd for year t, SCS_{nit} is the average linear somatic cell score for the nth cow in the ith herd for year t, $lact2_{nit}$ is a dummy variable for a second lactation cow (=1 if the nth cow in the ith herd is in her second lactation for year t, =0 otherwise), $lact3_{nit}$ is a dummy variable for a third or higher lactation cow (=1 if the nth cow in the ith herd is in her third or higher lactation for year t, =0 otherwise), $Cottonseed_{nit}$ is a dummy variable for cottonseed consumption (=1 if the nth cow in the ith herd consumed cottonseed in year t, =0 otherwise), $BeetPulp_{nit}$ is a dummy variable for beet pulp consumption (=1 if the nth cow in the ith herd consumed beet pulp in year t, =0 otherwise), $Oats_{nit}$ is a dummy variable for oat consumption (=1 if the nth cow in the ith herd consumed oats in year t, =0 otherwise), $Pasture_{nit}$ is a dummy variable for pasture consumption (=1 if the nth cow in the ith herd consumed pasture in year t, =0 otherwise), $allDDGS_{nit}$ is a dummy variable for the $Q\_allDDGS_{nit}$ consumption (=1 if the nth cow in the ith herd consumed wet distillers grains, dried distillers grains, or corn gluten in year t, =0 otherwise), $Barley_{nit}$ is a dummy variable for barley consumption (=1 if the nth cow in the ith herd

consumed barley in year t, =0 otherwise), $Soybeans_{nit}$ is a dummy variable for soybean

consumption (=1 if the nth cow in the ith herd consumed soybeans in year t, =0

otherwise), $PercentRoughageRange_{nit}$ is a dummy variable for an optimal percent

roughage of dietary DM (=1 if the nth cow in the ith herd in year t consumes a percent

roughage within the range of 40-60% dietary DM, =0 otherwise), and ε_{nit} is the error

term. As shown earlier in Equations 11-14, the composite variables for "protein,

vitamins, and minerals", corn, corn silage, and hay are continuous, so all variables with

"Q_" in the regressions designate continuous variables.[10]

When dairies feed their cattle, often times they feed a premixed feed. These

premixed feeds could likely be coded by some dairies under "complete ration" or

"protein, vitamins, and minerals", instead of separating out each individual feedstuff in

FINBIN. Because of this, the second regression, ECM Regression II, analyzed each

feedstuff without including the separated feedstuffs that could have likely been

confounded in the "all protein, vitamins, and minerals" variable. These feedstuffs, such as

cottonseed, beet pulp, DDGS, barley, and soybeans, were added to the "all protein,

vitamins, and minerals" variable to create a new composite variable, such that,

(19) $Q\_PVM\_II_{nit} = Q\_ProtVitMin_{nit} + Q\_CompleteRation_{nit} +$

$Q\_ProteinSupplement_{nit} + Q\_Cottonseed_{nit} + Q\_BeetPulp_{nit} +$

$Q\_allDDGS_{nit} + Q\_Barley_{nit} + Q\_Soybeans_{nit}$

---

[10] Q_PVM_I, $Q\_allCorn$, $Q\_allCornSilage$, and Q_allHay are continuous variables for feed quantities, as they have "Q_" at the beginning of their names. *Cottonseed, BeetPulp, Oats, Pasture, allDDGS, Barley, Soybeans*, and *PercentRoughageRange* are binary variables (=1 if fed, =0 otherwise).

where $Q\_PVM\_II_{nit}$ is the quantity consumed of the "all protein, vitamins, and minerals"

variable (Equation 14) along with the feeds that could have likely been confounded by

the nth cow in the ith herd for year t, $Q\_ProtVitMin_{nit}$ is the quantity consumed of

"proteins, vitamins, and minerals" by the nth cow in the ith herd for year t,

$Q\_CompleteRation_{nit}$ is the quantity consumed of "complete ration" by the nth cow in

the ith herd for year t, $Q\_ProteinSupplement_{nit}$ is the quantity consumed of protein

supplement by the nth cow in the ith herd for year t, $Q\_Cottonseed_{nit}$ is the quantity

consumed of cottonseed by the nth cow in the ith herd for year t, $Q\_BeetPulp_{nit}$ is the

quantity consumed of beet pulp by the nth cow in the ith herd for year t, $Q\_allDDGS_{nit}$ is

the quantity consumed of dried distillers grains, wet distillers grains, and corn gluten by

the nth cow in the ith herd for year t, Q_Barley_{nit} is the quantity consumed of barley by

the nth cow in the ith herd for year t, and $Q\_Soybeans_{nit}$ is the quantity consumed of

soybeans by the nth cow in the ith herd for year t.

ECM Regression II (Equation 20) illustrates the importance of collecting detailed

data from farms in order to have detailed results on the feeding decision. ECM

Regression II uses the new composite variable for protein, vitamins, and minerals created

in Equation 19 instead of the dummy variables that were found to likely be confounded in

the "all protein, vitamins, and minerals" variable, such that,

$$(20) \quad ECM_{nit} = \beta_0 + \beta_1 SCS_{nit} + \beta_2 lact2_{nit} + \beta_3 lact3_{nit} + \beta_4 Q\_PVM\_II_{nit} +$$
$$\beta_5 Q\_allCorn_{nit} + \beta_6 Q\_allCornSilage_{nit} + \beta_7 Q\_allHay_{nit} + \beta_8 Oats_{nit} +$$
$$\beta_9 Pasture_{nit} + \beta_{10} PercentRoughageRange_{nit} + \varepsilon_{nit}.$$

The third regression, ECM Regression III, analyzed only the continuous variables

with 70,000 observations or more, getting rid of all dummy variables for feeds. All feeds

that were included as dummy variables in ECM Regression I (Equation 18) were added to

the "all protein, vitamins, and minerals" variable created in Equation 14, such that,

(21) $\quad Q\_PVM\_III_{nit} = Q\_ProtVitMin_{nit} + Q\_CompleteRation_{nit} +$

$Q\_ProteinSupplement_{nit} + Q\_Cottonseed_{nit} + Q\_BeetPulp_{nit} +$

$Q\_allDDGS_{nit} + Q\_Barley_{nit} + Q\_Soybeans_{nit} + Q\_Oats_{nit} + Q\_Pasture_{nit}$

where $Q\_PVM\_III_{nit}$ is the quantity consumed of the "all protein, vitamins, and minerals"

variable along with the feeds that could have likely been confounded, oats, and pasture by

the nth cow in the ith herd for year t, $Q\_ProtVitMin_{nit}$ is the quantity consumed of

"proteins, vitamins, and minerals" by the nth cow in the ith herd for year t,

$Q\_CompleteRation_{nit}$ is the quantity consumed of "complete ration" by the nth cow in

the ith herd for year t, $Q\_ProteinSupplement_{nit}$ is the quantity consumed of protein

supplement by the nth cow in the ith herd for year t, $Q\_Cottonseed_{nit}$ is the quantity

consumed of cottonseed by the nth cow in the ith herd for year t, $Q\_BeetPulp_{nit}$ is the

quantity consumed of beet pulp by the nth cow in the ith herd for year t, $Q\_allDDGS_{nit}$ is

the quantity consumed of dried distillers grains, wet distillers grains, and corn gluten by

the nth cow in the ith herd for year t, Q_Barley_{nit} is the quantity consumed of barley by

the nth cow in the ith herd for year t, $Q\_Soybeans_{nit}$ is the quantity consumed of

soybeans by the nth cow in the ith herd for year t, Q_Oats_{nit} is the quantity consumed of

oats by the nth cow in the ith herd for year t, and $Q\_Pasture_{nit}$ is the quantity consumed

of pasture by the nth cow in the ith herd for year t.

ECM Regression III (Equation 22) is likely the most accurate representation of how the feedstuffs in FINBIN impact ECM, as it includes the variables with the highest number of observations and likely no variables are confounded in this regression. ECM Regression III differs from ECM Regression II as it utilizes the newest composite variable for protein, vitamins, and minerals (Equation 21) and no longer includes any dummy variables for feedstuffs. Although it is likely the most accurate portrayal of the feeding decision, it does not allow us to discern the specific management characteristics we are trying to highlight since the individual feedstuffs are grouped together.

(22) $ECM_{nit} = \beta_0 + \beta_1 SCS_{nit} + \beta_2 lact2_{nit} + \beta_3 lact3_{nit} +$

$\beta_4 Q\_PVM\_III_{nit} + \beta_5 Q\_allCorn_{nit} + \beta_6 Q\_allCornSilage_{nit} +$

$\beta_7 Q\_allHay_{nit} + \beta_8 pPercentRoughageRange_{nit} + \varepsilon_{nit}.$

Table 1 defines the variables in the three regressions and which regression they are specifically used in.

Table 1: ECM Regression Variables, Definitions and Inclusion in ECM Regressions.[1,2]

Variable	Definition	ECM Reg I	ECM Reg II	ECM Reg III
ECM	Annual Energy Corrected Milk, lbs.[1]	Yes	Yes	Yes
SCS	Average Annual Somatic Cell Score, linear score	Yes	Yes	Yes
Lactation 1	=1 if in her first lactation, =0 otherwise	No	No	No
Lactation 2	=1 if in her second lactation, =0 otherwise	Yes	Yes	Yes
Lactation 3	=1 if in her third or higher lactation, =0 otherwise	Yes	Yes	Yes
Q_PVM_I	Quantity of "protein, vitamins, and minerals", "complete ration", and protein supplement, lbs.	Yes	No	No
Q_PVM_II	Quantity of "all protein, vitamins, and minerals" and confounded feeds, lbs.	No	Yes	No
Q_PVM_III	Quantity of "all protein, vitamins, and minerals" and all feeds used as dummies in Regression I, lbs.	No	No	Yes
Q_allCorn	Quantity of corn and ear corn, lbs.	Yes	Yes	Yes
Q_allCornSilage	Quantity of corn silage and sweet corn silage, lbs.	Yes	Yes	Yes
Q_allHay	Quantity of all hay types	Yes	Yes	Yes
Cottonseed	=1 if consumes cottonseed, =0 otherwise	Yes	No	No
BeetPulp	=1 if consumes beet pulp, =0 otherwise	Yes	No	No
Oats	=1 if consumes oats, =0 otherwise	Yes	Yes	No
Pasture	=1 if consumes pasture, =0 otherwise	Yes	Yes	No
allDDGS	=1 if consumes distillers grains, =0 otherwise	Yes	No	No
Barley	=1 if consumes barley, =0 otherwise	Yes	No	No
Soybeans	=1 if consumes soybeans, =0 otherwise	Yes	No	No
Percent Roughage Range	=1 if the percent roughage of dietary dry matter is within the range of 40-60%, =0 otherwise	Yes	Yes	Yes

[1] ECM is calculated using a formula from Dairy Records Management Systems' DHI Glossary (2014) such that,

$$ECM = (0.327 * MilkYield) + (12.95 * FatYield) + (7.65 * ProteinYield)$$

where *ECM* is Energy Corrected Milk (lbs.), *MilkYield* is lbs. of milk produced, *FatYield* is lbs. of fat produced, and *ProteinYield* is lbs. of protein produced.

[2] Feed variables with "Q_" at the beginning represent continuous quantities of that feedstuff. Feed variables without "Q_" at the beginning are binary variables.

5.1.3 *Explanatory Variable Expectations for the ECM Regressions*

The lactation dummies were expected to have positive impacts on ECM, with the third and higher lactation cows having a higher magnitude than the second lactation cows. This is because cows are expected to increase in milk yield year-over-year as they increase in maturity (age and number of calves). SCS could have either a positive or negative impact on ECM. High-producing cows tend to be higher in SCS. However, a high SCS could relate directly to animal health issues, causing decreased milk production, increased costs, and increased risk of culling.

Of the feed variables used in our ECM regressions, the "protein, vitamins, and minerals" composite variables, corn, corn silage, and hay were all expected to have positive impacts on ECM. The magnitude was not expected to be as high as the binary feed variables included in the regressions since these are continuous variables. Binary variables have a discrete value of zero or one, causing them to respond differently than continuous variables. The binary feeds accounted for the yearly differences in ECM production by feeding or not feeding a specific feedstuff, while the continuous feed variables analyzed a one-unit change, or one pound, in feed consumption for the entire year. Corn silage and corn were expected to have the highest magnitudes out of the continuous feed variables, and thus the greatest impacts on ECM. This is because corn silage and corn have relatively high values for energy, which would increase ECM production. Of the binary feed variables, cottonseed, beet pulp, DDGS, and soybeans were expected to have a positive relationship with ECM, while oats, pasture, and barley were expected to have a negative relationship with ECM. Cottonseed and beet pulp are both good sources of energy in the diet, and when balanced correctly in a ration are very

likely to improve ECM. Soybeans and DDGS are high in protein, thus improving ration protein levels and increasing ECM. Oats and barley were expected to be negative because these feeds improve ECM at levels less than corn as they are lower in energy than corn and corn is more commonly fed in the herds in the dataset. Pasture is commonly fed as a cheap source of feed, rather than a nutritionally dense feed to improve production, and was expected to have a negative impact due to its low energy and nutritional value. The binary variable for percent roughage being in the optimal range was expected to be positive, as cows who consume a percent roughage within the range of 40-60% have previously shown to have higher milk yield and milk fat levels (Grant and Kononoff, 2007; Journet and Chilliard, 1985; NRC, 2001; Sutton, 1989; Thomas and Martin, 1988).

5.2   Step 2 – Cow Nutrition's Impact on Financial Resiliency

5.2.1   Resiliency Model Setup

In the first step of this analysis, the feeding decision's impact on ECM was analyzed to determine the feeds that had strong impacts on ECM, while simultaneously informing the decision of the feeds and nutrition factors that should be considered in the analysis of resilient dairy farms. Performing this study in two separate steps allowed two main conclusions to be drawn from the data based on quantities and expenses of feeds – the types of feeds that have the largest impact on ECM (considering quantity consumed) and the types of feeds that have the largest impact on dairy farm resiliency (considering quantity consumed and price).

A similar model to Robert (2019) was estimated with the additional detailed feed data included using total expenses of feedstuffs, rather than quantities or per unit

expenses. This was done to capture the results from the ECM models while also accounting for the economic feasibility of using these feeds. There has been little to no research on this as collecting actual expenses for feeds, as well as quantities, over multiple years is cumbersome. FINBIN allows us to do this by taking the average feed cost for the year based on regional differences. Monthly grain or feed prices are compiled at a certain time each month and then are averaged across the year. This is then applied to the quantity reported to get the total expense reported in FINBIN. Feed allocation methods were then created to allocate the feed consumption in different ways rather than taking a simple average, as a cow consumes more feed when she is producing more milk.

To estimate the impact of farm characteristics on dairy farm resiliency, two measures of financial resiliency were used. This followed Roberts (2019), which also estimated the impact of farm characteristics on dairy farm resiliency. Adjusted net farm income (NFI) ratio and rate of return on assets (RROA) were ranked for each farm each year. If a farm ranked in the top 25% of the farms based on adjusted NFI ratio or RROA for a majority of the years they were in the dataset, they were considered resilient and received an indicator value of 1.[11] Farms were only considered resilient for the two indicator variables if they were in the dataset for at least three years. For example, if a farm was in the dataset for only two years and ranked in the top 25% of herds for one of those two years, they were not considered resilient.

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[11] As performed in Roberts (2019), an indicator variable was created for farms who ranked in the top 25% of the farms based on both adjusted NFI ratio and RROA for a majority of the years they were in the dataset. Due to our feed allocation methods, there were not enough observations to make this group significantly different, so it was not used in further analysis.

A between-effects model was used to measure the impact of farm characteristics on each of the two resiliency indicators to estimate the cross-sectional information in the data (StataCorp, 2019). The between-effects model measures the effect of the explanatory variables as they change between farms, rather than within. Roberts (2019) used a two-stage least-squares model while a between-effects model is utilized for this analysis. A between-effects estimation allows the dependent variable to measure farm resiliency across multiple years in the dataset while looking at data from each of those years. StataCorp (2019) states that the between estimator performs the estimation of

$$(23) \qquad \bar{y}_i = \alpha + \bar{x}_i\beta + v_i + \bar{\varepsilon}_i \, ,$$

where $\bar{y}_i$ is the average of the dependent variable measured for the ith entity across all time periods, $\bar{x}_i$ is the average of the explanatory variable measured for the ith entity across all time periods, β is the coefficient on the explanatory variable, and $v_i + \bar{\varepsilon}_i$ is the error term.

Two models – a Detailed Feed Model and a Composite Feed Model – were estimated for each resiliency measure and each feed weighting dataset to better understand nutrition's impact on dairy farm resiliency. The feed expense variables from the nutrition factors were the only explanatory variables that differed between the two types of models. Both models included expenses of certain feedstuffs and a dummy variable for the percent roughage being in the optimal range of 40-60% of dietary DM. The key difference between these two models was the level of detail of the feedstuffs' expenses. The first model, the Detailed Feed Model, included the detailed feed data, as used in ECM Regression I (Equation 18). Total expenses of feedstuffs, including "all

protein, vitamins, and minerals", "all corn", "all corn silage", "all hay", cottonseed, beet pulp, oats, pasture, "all DDGS", barley, and soybeans, were used in this model as continuous variables. The Detailed Feed Model was performed to capture the effect of specific feedstuffs on resiliency.

The second model, the Composite Feed Model, followed the same method of ECM Regression III (Equation 22). The Composite Feed Model had less detailed feed expenses in its regression, using only total feed expenses for "PVM_III" (Equation 21; combines "all protein, vitamins, and minerals" with all feeds used as dummies in ECM Regression I), "all corn" (corn and ear corn), "all corn silage" (corn silage and sweet corn silage), and "all hay" (all hay types combined). These four feed expense variables were used because they had the highest number of observations in the dataset. The detailed feeds were added to the "all protein, vitamins, and minerals" variable because feeds could have been confounded, allowing us to potentially get more accurate results by excluding them from analysis. No model was run that followed the level of detail from ECM Regression II, as ECM Regressions I and III did the best job of explaining the differences in the level of detailed feed data illustrated in the dataset.

Following Roberts (2019), all explanatory variables were grouped into four categories plus a fifth category to consider the feeding decision. Human resources and farm financials followed identical format as Roberts (2019). Herd structure was similar to Roberts (2019); however, the variables for the percentage of cows who breakeven in each lactation were not included, as performing a more accurate capturing of nutritional effects on resiliency was of greater concern. The category that has been enhanced with this work is animal health. Roberts (2019) initially considered milk yield, fat and protein

concentration, death rate, cull rate, and average feed expense per cow (allocated equally). In the current study, animal health was split into two separate categories: animal health and nutrition. Animal health used ECM as opposed to milk yield and fat and protein concentration to mirror the dependent variable from the first stage of this analysis. Nutrition was added to capture the nutrition-specific characteristics that impact resiliency, such as feed expenses, as allocated by the three weighting methods, and the percent roughage in the diet. Equation 24 presents the generic resiliency regression, such that,

$$(24) \quad Resiliency_i^{measure} = f(Human\ Resources,\ Animal\ Health,$$

$$Herd\ Structure,\ Financials,\ Nutrition) + \varepsilon_{nit}$$

where $Resiliency_i^{measure}$ is the resiliency *measure* (adjusted NFI ratio or RROA) for herd *i*; $Human\ Resources$ includes *Age of Operator, Age of Operator Squared, Second Generation, Dairy Initiative,* and *Hired Labor per Cow*; $Animal\ Health$ includes *ECM, Death Rate*, and *Cull Rate*; $Herd\ Structure$ includes *Herd Size, Acres per Cow,* and *Percent Crop Acres Owned*; $Financials$ includes *Debt to Asset Ratio, Working Capital per Cow,* and *Interest Expense per Cow*; $Nutrition$ includes individual feedstuff expenses and *Percent Roughage Range*; and ε_{nit} is the error term. The specific explanatory variables and their definitions can be found in Table 2.

Table 2: Resiliency Model Variables, Definitions and Inclusion in Resiliency Models.

Variable	Definition	Detailed Feed	Composite Feed
NFI Resiliency	=1 if adjusted NFI ratio ranks in the top 25% of herds for the majority of years, =0 otherwise	Yes	Yes
RROA Resiliency	=1 if RROA ranks in the top 25% of herds for the majority of years, =0 otherwise	Yes	Yes
Age of Operator	Age of the primary operator	Yes	Yes
Age of Operator Squared	Age of the primary operator squared	Yes	Yes
Second Generation	=1 if a second generation operator works on the farm, =0 otherwise	Yes	Yes
Dairy Initiative	=1 if the farm participated in the Minnesota Dairy Initiative Program, =0 otherwise	Yes	Yes
Hired Labor per Cow	Total hired labor cost divided by the average number of cows on the farm, $/cow	Yes	Yes
ECM	Total annual energy corrected milk, lbs.	Yes	Yes
Death Rate	Percent of the herd that died, multiplied by 100	Yes	Yes
Cull Rate	Percent of the herd that was culled (not including deaths), multiplied by 100	Yes	Yes
Herd Size	Average number of cows per farm per year, cows	Yes	Yes
Acres per Cow	Total acres operated divided by the average number of cows on the farm, acres/cow	Yes	Yes
Percent Crop Acres Owned	Percent of crop acres owned out of total crop acres operated, multiplied by 100	Yes	Yes
Debt to Asset Ratio	Total liabilities divided by total assets, multiplied by 100	Yes	Yes
Working Capital per Cow	Total working capital divided by the average number of cows on the farm, $/cow	Yes	Yes
Interest Expense per Cow	Total interest expense divided by the average number of cows on the farm, $/cow	Yes	Yes
E_PVM_I	Total expense of "protein, vitamins, and minerals", "complete ration", and protein supplement, $	Yes	No
E_PVM_III	Total expense of "all protein, vitamins, and minerals" and all feeds used as dummies in Regression I of the ECM regressions, $	No	Yes
E_allCorn	Total expense of corn and ear corn, $	Yes	No
E_allCornSilage	Total expense of corn silage and sweet corn silage, $	Yes	No
E_allHay	Total expense of all hay types, $	Yes	No
E_Cottonseed	Total expense of cottonseed, $	Yes	No

E_BeetPulp	Total expense of beet pulp, $	Yes	No
E_Oats	Total expense of oats, $	Yes	No
E_Pasture	Total expense of pasture, $	Yes	No
E_allDDGS	Total expense of dried distillers grain, wet distillers grains, and corn gluten feed, $	Yes	No
E_Barley	Total expense of barley, $	Yes	No
E_Soybeans	Total expense of soybeans, $	Yes	No
Percent Roughage Range	=1 if the percent roughage of dietary DM is within the range of 40-60%, =0 otherwise	Yes	Yes

5.2.2 Explanatory Variable Expectations for the Resiliency Models

Of the human resource factors, *age of operator, second generation,* and *hired labor per cow* were expected to have a negative impact on resiliency, while *dairy initiative* was expected to be positive. The principal operator's age increasing could improve resiliency, as more knowledge and wisdom is gained over time. However, an increasing age could also mean that farmers become less likely to make changes on their farm over time, causing resiliency to be less likely. *Age of operator squared* was included, as age was expected to decrease the likelihood of resiliency at an increasing rate as the primary operator gets older. *Second generation* was a binary variable for two generations working on the farm as primary and secondary operators. Having the second generation working on the farm had an expected negative relationship with resiliency, as two or more households on the farm could mean splitting income more ways, decreasing the total returns back to the farm. Increasing hired labor per cow was expected to be negative as a lower labor cost would result in higher income. *Dairy initiative* was a binary variable used as a proxy for overall dairy education by Minnesota dairy farmers. Farmers who participated in the Minnesota Dairy Initiative Program were expected to have a higher likelihood of resiliency, as these farmers were more likely to be progressive operators seeking education and improvements for their operations. Not only does this program teach farmers how to run more efficient and profitable operations, but also the farmers who are more likely to join are the progressive farmers willing to make changes and constantly looking for improvements for their farms. Many of the signs on the explanatory variables had similar expectations to what was found in Roberts' (2019)

thesis. Including these in the resiliency analysis of this study was tested to see if adding the nutritional detail changes the sign and magnitude of these models.

In the animal health category, *ECM* and *cull rate* were expected to have positive signs on resiliency, while *death rate* was expected to be negative. A higher ECM means greater revenues back to the farmer. Roberts (2019) found that higher concentrations of milk fat and protein were more important to resiliency than strictly milk yield, which could cause ECM to have a negative sign on resiliency. *Cull rate* was expected to be positive, as farmers could be making better decisions of which cows to cull and replacing them with more profitable cows. *Cull rate* did have potential to be negative, however, as a negative sign on cull rate would indicate there are too many cows with problems, such as low milk production, low reproduction efficiency, or health concerns, causing the need for culling to be more of a negative problem than a positive solution. *Death rate* was expected to be negative, as a lower death rate meant healthier and longer-lasting cows with lower costs and increased revenue.

For the herd structure factors, *acres per cow* and *percent crop acres owned* were expected to have positive impacts on resiliency, while *herd size* had no expected sign. A positive sign was expected for *acres per cow* because lower feed expenses, resulting in greater resiliency, could come from more acreage to produce homegrown feeds. *Percent crop acres owned* was expected to have a positive relationship with resiliency, as a higher percentage owned could mean a greater amount of equity, resulting in lower yearly costs for liabilities and higher profitability. Although, a negative impact on resiliency for *percent crop acres owned* could be explained by resilient farms consistently looking to expand and make improvements for their herd, thus having lower equity but still leading

to resiliency. *Herd size* had no expected sign, as larger herds could have lower marginal costs shared across all cows, while a smaller herd could have increased knowledge of the farm and its cows.

The signs on the financial indicators were expected to be positive for *debt to asset ratio* and *working capital per cow* and negative for *interest expense per cow*. Although at first glance a positive sign on debt to asset ratio causes concern for high liabilities, it could indicate a lender's trust in a farm by granting them larger loans. *Working capital per cow* was expected to be positive as higher working capital signifies greater liquidity and could directly result in higher income per cow. *Interest expense per cow* was expected to be negative, as farms with lower interest expense could have lower liabilities, stronger credit history, lower interest rates, or fund their improvements through their own profits, making them more resilient.

The feed variables used in the resiliency models considered both the quantities and per unit expenses of each feedstuff. When considering both the quantities and per unit expenses, the signs on the expenses of corn silage and hay were expected to be positive, as these feeds are relatively cheap when compared to other feeds commonly fed in dairy cattle diets. Corn silage expense was especially expected to be positive because it is a cheap source of energy, commonly homegrown, and fed frequently on dairy farms. The sign on the expenses of the "protein, vitamins, and minerals" variables were expected to be negative, as we could not distinguish exactly which feeds were recorded in this variable. If the costs were too high, this variable would most likely have a negative sign on resiliency. Although corn is a great source of energy and would increase ECM production, corn expense was expected to be negative, because corn is likely more

expensive. It is difficult to determine the specific signs on the remaining feedstuffs in the Detailed Feed Model, as there were fewer observations of these feedstuffs and the mean yearly quantities of consumption were much smaller when compared to the "protein, vitamins, and minerals" variables, corn, corn silage, and hay. The lower mean quantities could mean that these feeds were not fed across the entire year when reported for the entire year, potentially resulting in inaccurate measurements. Lastly, *percent roughage range* was expected to have a positive impact on resiliency, as a percent roughage in the optimal range should result in healthier, high-producing cows, increasing the likelihood of resiliency.

Chapter 6

Results

6.1   Step 1 – Cow Nutrition's Impact on Energy Corrected Milk

6.1.1   *Analysis of ECM Regression Summary Statistics*

The dataset consists of an unbalanced panel of 100,045 cow observations across 82 farms from 2012 to 2018. Table 3 shows the summary statistics for all variables included in the three ECM regressions, split by feed allocation method. More detailed summary statistics for all feeds considered for the ECM regressions can be found in Appendix C.

A large portion of the cows in the dataset are considered first lactation (42%), and the average annual ECM is 17,540.64 pounds per cow per year. The cows in our dataset have a relatively low SCS of 2.84, which equates to a somatic cell count of 89,502 cells per milliliter. There are more than 80,000 observations greater than zero for each of our continuous feed variables for the EW and PGW feed datasets, and greater than 70,000 observations for the VW feed dataset. The continuous variable with the greatest number of observations is corn silage, as this is a very commonly utilized feed. Our dummy variables for specific feedstuffs show that these feeds are fed in the range of 1 to 17% of the time. DDGS are the most common of the dummy variables at 14-17% depending on the feed weighting dataset, and soybeans and barley are the least common at 1% and 2%, respectively. There are approximately 78,000 to 88,000 observations of percent roughage in the three datasets, and 55% of the cows consume a percent roughage in the optimal range of 40-60% of dietary DM. It is important to note that these summary statistics are

at the cow level rather than the herd level, meaning that these values are representative of individual cows over the years. For example, although 55% of the cows consume a percent roughage in the optimal range, this does not necessarily mean that 55% of the farms feed a percent roughage in the optimal range.

Table 3: Summary Statistics for the Dependent and Explanatory Variables in the ECM Regressions for the EW, PGW, and VW Feed Datasets.[1,2]

Feed Variable	N	EW Mean	Std. Dev.	N	PGW Mean	Std. Dev.	N	VW Mean	Std. Dev.
ECM	85,743	17,540.64	9,334.28	85,743	17,540.64	9,334.28	85,743	17,540.64	9,334.28
SCS	95,354	2.84	1.84	95,354	2.84	1.84	95,354	2.84	1.84
Q_PVM_I	100,045	3518.59	3035.28	100,045	3515.2	3238.28	100,045	3514.65	3384.63
Q_PVM_I (greater than 0)	90,176	3903.67	2952.62	90,050	3905.37	3182.24	80,354	4375.93	3239.45
Q_PVM_II	100,045	3986.08	3514.05	100,045	3982.96	3748.84	100,045	3982.44	3925.74
Q_PVM_II (greater than 0)	90,237	4419.33	3431.62	90,121	4421.56	3696.23	80,452	4952.3	3789.67
Q_PVM_III	100,045	4061.26	3528.56	100,045	4058.16	3769.25	100,045	4057.59	3947.36
Q_PVM_III (greater than 0)	90,395	4494.81	3439.64	90,279	4497.16	3710.78	80,614	5035.62	3796.37
Q_allCorn	100,045	2732.68	2150.48	100,045	2727.68	2328.25	100,045	2729.1	2434.69
Q_allCorn (greater than 0)	89,376	3058.88	2044.2	88,428	3086.02	2242.1	79,045	3454.15	2235.65
Q_allCornSilage	100,045	4554.88	3318.98	100,045	4554.86	3601.32	100,045	4548.5	3780.12
Q_allCornSilage (greater than 0)	91,516	4979.38	3150.95	91,516	4979.36	3473.39	81,053	5614.29	3413.77
Q_allHay	100,045	2074.17	2759.36	100,045	2074.88	2896.73	100,045	2074.83	2981.92
Q_allHay (greater than 0)	83,796	2476.37	2845.08	83,796	2477.23	3003.58	74,658	2780.37	3154.98
		Proportion			**Proportion**			**Proportion**	
Lactation 1	100,045	0.42	0.49	100,045	0.42	0.49	100,045	0.42	0.49
Lactation 2	100,045	0.26	0.44	100,045	0.26	0.44	100,045	0.26	0.44
Lactation 3	100,045	0.32	0.47	100,045	0.32	0.47	100,045	0.32	0.47
Cottonseed	92,768	0.13	0.34	92,775	0.13	0.34	99,574	0.11	0.31
BeetPulp	93,074	0.12	0.32	92,983	0.12	0.32	99,585	0.10	0.30
Oats	93,054	0.06	0.23	92,892	0.06	0.23	99,634	0.05	0.22
Pasture	93,255	0.05	0.22	93,013	0.05	0.22	99,642	0.04	0.20
allDDGS	93,357	0.17	0.37	93,059	0.17	0.37	99,685	0.14	0.35

Barley	93,349	0.02	0.14	93,000	0.02	0.14	99,669	0.02	0.13
Soybeans	93,333	0.01	0.11	93,047	0.01	0.11	99,675	0.01	0.10
Percent Roughage Range	88,498	0.55	0.50	88,301	0.55	0.50	78,183	0.55	0.50

[1] Values for ECM, SCS, and the lactation dummies do not change across the different feed weighting datasets.

[2] Summary statistics for continuous quantities of feedstuffs are reported for all observations. A separate entry is added below the continuous quantities of feedstuffs for summary statistics of only observations greater than zero.

6.1.2 *Analysis of ECM Regression Results*

The three models specified in equations 18, 20, and 22 were run for all three feed weighting datasets to analyze the impact of cow-level feedstuffs and cow characteristics on ECM. Each of the regressions had a relatively high total R-squared value for all of the feed allocation methods, as shown in Table 4. Approximately 44.5% to 66.8% of the variation in ECM was explained by these regressions. This is large considering 55% of the variation in milk production is due to genetics, which is recognized partially in the cow characteristics included in the regressions. The highest R-squared values were for the VW feed allocation, and the lowest R-squared values were for the EW feed allocation. This was expected, as this corresponds to the order of the level of detail of the feed allocation in each dataset. The total R-squared values increased within a dataset moving from ECM Regression I to ECM Regressions II and III. As discussed earlier, this is likely because certain variables are confounded within the "protein, vitamins, and minerals" and "complete ration" variables, causing the detailed feed data to be slightly inaccurate. With fewer variables, ECM Regressions II and III do not double count specific feedstuffs, causing a higher total R-squared. Meanwhile, the values for R-squared within decreased when moving from ECM Regression I to ECM Regressions II and III, likely because there were fewer variables used in the regressions with less detailed feed data.

All three regressions used the cow characteristic variables of SCS and lactation dummies to control for known factors affecting a cow's ECM production. Surprisingly, the regressions for each feed allocation method found different signs and significance for SCS. The EW method found that an additional unit on the linear score scale of SCS

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decreased ECM by a range of 62.4 to 85.5 pounds per cow per year. In contrast, the VW method found that an additional unit on the linear score scale increased ECM by 51.6 to 64.9 pounds per cow per year. The coefficient on SCS for the PGW method was not significant at the 5% level for all three regressions. The positive sign for the VW method is likely because cows who produce higher levels of milk are prone to being higher in SCS. The greater detail in feed data for the VW dataset compared to the EW dataset could be why there is a difference in the signs for SCS.

Similar results were found in the signs and magnitudes of the lactation dummies for all allocation methods. All coefficients on the lactation dummies for each regression were significant at the 1% level. Moving from the first lactation to the second lactation increased ECM by a range of 315.9 to 1,748 pounds per cow per year, and moving from the first lactation to the third or higher lactations increased ECM by a range of 1,189 to 2,438 pounds per cow per year. All three datasets were consistent with our expectations of ECM improving year-over-year for each cow as she grows in maturity and has more calves. The PGW method saw the smallest magnitudes for the lactation dummies, followed by the VW method and the EW method.

Most feed variables stayed consistent in sign between regressions and allocation methods. There was a greater difference in magnitude between allocation methods than there was between the ECM regression types. The differences in magnitude between allocation methods along with the higher R-squared values for the PGW and VW datasets suggest that the EW feed dataset is not appropriate for measuring cow-level feed consumption.

All continuous feed variables were significant at the 1% level, had positive signs, and had similar magnitudes across all regressions. The magnitudes of the continuous feed variables were much smaller than those for the dummy feed variables, as the continuous variables represent the impact of a marginal change in each feedstuff's consumption. Corn silage and corn had the highest magnitudes of the four continuous variables analyzed in these regressions. Increasing corn silage consumption by an additional pound per cow year increased ECM within the range of 1.245 to 1.395 pounds per cow per year. Although this is a small amount of increased ECM, one must recognize that this is a marginal change in corn silage consumption by a small amount of a single pound for one cow for an entire year. Additionally, increasing corn consumption by an additional pound per cow per year increased ECM within the range of 0.900 to 1.285 pounds per cow per year. The quantity of corn showed the biggest differences in magnitude across allocation methods but stayed relatively consistent within each allocation method.

Percent roughage within the range of 40-60% (*Percent Roughage Range*) also proved to be important for all allocation methods with a high positive magnitude. By feeding roughage between 40% and 60% of dietary DM, ECM increased by a range of 1,279 to 1,474 pounds per cow per year. This is in accordance with previous research regarding the optimal range of percent roughage in the diet (Grant and Kononoff, 2007; Journet and Chilliard, 1985; NRC, 2001; Sutton, 1989; Thomas and Martin, 1988; Weiss and Shockey, 1991).

Across all three feed allocation methods, oats and barley were not significant at the 5% level in ECM Regression I and oats was not significant at the 5% level in ECM Regression II. Of the remaining binary feed variables that were significant at the 5%

level, beet pulp and DDGS had opposite signs of what was expected. Feeding beet pulp was shown to decrease ECM by a range of 2,170 to 3,063 pounds per cow per year. Although beet pulp is often fed as a good and cheap source of energy, its low cost could cause it to be fed to fill a ration rather than to balance it. Feeding DDGS was shown to decrease ECM by a range of 1,368 to 2,146 pounds per cow per year. Although DDGS is fed as a protein source, it is a highly inconsistent byproduct, causing its nutritional value to be variable while trying to balance it within a ration. In addition, feeding DDGS at high levels can result in lower fat levels, lowering ECM (Díaz-Royón and García, 2012). Another reason why the signs on beet pulp and DDGS could be different from what was expected could be because these variables were being impacted by other factors in the data or could be confounded in other variables. This is evident in how the R-squared values were actually highest for ECM Regression III even though it had the fewest number of variables.

Table 4: Fixed-Effects Regression Results Using ECM as the Dependent Variable for the EW, PGW, and VW Feed Datasets across Three Levels of Feed Detail.[1]

Explanatory Variable	Equal Weighting			Production Group Weighting			Volume Weighting		
	ECM I	ECM II	ECM III	ECM I	ECM II	ECM III	ECM I	ECM II	ECM III
SCS	-62.38**	-82.28**	-85.53**	-14.80	-26.11	-28.88	64.92**	52.13**	51.61**
	(20.96)	(20.93)	(20.84)	(18.20)	(18.25)	(18.20)	(15.67)	(15.83)	(15.79)
lact2	1,748.08**	1,726.20**	1,727.63**	369.83**	315.86**	320.03**	1,077.54**	1,094.64**	1,102.83**
	(68.34)	(68.01)	(67.71)	(61.00)	(60.97)	(60.80)	(50.84)	(51.22)	(51.08)
lact3	2,356.66**	2,412.76**	2,438.17**	1,173.90**	1,188.69**	1,219.50**	1,680.70**	1,777.64**	1,817.07**
	(81.84)	(80.91)	(80.61)	(72.28)	(71.83)	(71.66)	(61.12)	(61.17)	(61.02)
Q_PVM_I	0.652**			0.602**			0.630**		
	(0.012)			(0.010)			(0.008)		
Q_PVM_II		0.604**			0.554**			0.552**	
		(0.011)			(0.009)			(0.008)	
Q_PVM_III			0.614**			0.564**			0.560**
			(0.011)			(0.009)			(0.008)
Q_allCorn	0.900**	0.947**	0.934**	1.230**	1.285**	1.271**	1.036**	1.097**	1.082**
	(0.022)	(0.022)	(0.022)	(0.020)	(0.019)	(0.019)	(0.016)	(0.016)	(0.016)
Q_allCornSilage	1.326**	1.313**	1.311**	1.262**	1.247**	1.245**	1.395**	1.385**	1.385**
	(0.016)	(0.016)	(0.016)	(0.013)	(0.013)	(0.013)	(0.011)	(0.011)	(0.011)
Q_allHay	0.371**	0.277**	0.280**	0.316**	0.243**	0.244**	0.320**	0.249**	0.249**
	(0.017)	(0.017)	(0.016)	(0.013)	(0.013)	(0.013)	(0.011)	(0.011)	(0.011)
Cottonseed	843.76**			683.56**			489.03**		
	(153.91)			(131.12)			(111.92)		
BeetPulp	-3,062.50**			-2,428.77**			-2,170.38**		
	(173.79)			(147.24)			(127.86)		
Oats	-155.38	-166.44		13.22	-74.76		-33.72	-167.06	
	(202.83)	(203.77)		(167.65)	(168.46)		(142.28)	(143.92)	
Pasture	-1,082.03*	-1,207.48**		-1,333.09**	-1,455.95**		1,426.84**	-1,501.94**	
	(424.34)	(426.50)		(369.17)	(371.11)		(328.71)	(332.89)	
allDDGS	-2,146.14**			-1,527.71**			-1,367.97**		
	(130.77)			(113.99)			(95.66)		
Barley	-414.25			-416.72			-445.13		

	(324.21)			(287.40)			(249.74)		
Soybeans	1,538.98**			1,110.85**			1,977.79**		
	(340.92)			(285.15)			(250.12)		
Percent Roughage Range	1,471.43**	1,473.94**	1,458.50**	1,279.30**	1,306.18**	1,302.28**	1,345.94**	1,365.59**	1,353.77**
	(75.61)	(74.53)	(74.18)	(66.24)	(65.76)	(65.52)	(56.03)	(56.26)	(55.97)
N (Total)	74,930	75,525	75,809	75,000	75,326	75,471	75,618	75,822	75,876
N (Groups)	35,371	35,401	35,522	35,510	35,542	35,638	35,294	35,309	35,328
R^2 (Within)	0.587	0.580	0.582	0.700	0.696	0.697	0.762	0.755	0.756
R^2 (Total)	0.445	0.476	0.477	0.554	0.576	0.577	0.655	0.668	0.668

Note: The quantities below the estimates are the standard errors.

*=Significant at the 5% level, **=Significant at the 1% level

[1] Three regressions were run for each feed allocation method: (ECM I) all important feed variables separated out, (ECM II) feed variables separated out besides ones found in ECM I that are likely confounded in "all protein, vitamins, and minerals", and (ECM III) only continuous variables with 70,000 observations or more.

6.2   Step 2 – Cow Nutrition's Impact on Financial Resiliency

6.2.1   Analysis of Resiliency Model Summary Statistics

As stated earlier, the complete dataset is an unbalanced panel of 100,045 cow observations across 82 farms over 7 years. Of those 82 farms, 19 farms (11,577 cow observations) were considered resilient by the adjusted NFI ratio and 11 farms (13,417 cow observations) were considered resilient by the RROA. The lower number of farms with the higher number of cow observations when comparing resiliency by adjusted NFI ratio versus RROA suggests that herd size is much smaller for farms that are resilient by adjusted NFI ratio. This is confirmed in the summary statistics tables, Tables 5 and 6.

The summary statistics reported in Tables 5 and 6 show that there are key differences between the resiliency indicators. Herd size is much smaller, on average, for cows within NFI resilient herds than RROA resilient herds (111 cows versus 279 cows). Age of operator, age of operator squared, ECM, hired labor per cow, and death rate are all lower, on average, for cows within NFI resilient herds (Table 5) when compared to those who are considered RROA resilient (Table 6). In addition, cows within the NFI resilient herds, on average, are higher in the dairy initiative indicator, debt to asset ratio, working capital per cow, and interest expense per cow than cows in the RROA resilient herds. Cows in NFI resilient farms have a higher mean acres per cow and a higher mean percent of crop acres owned when compared to non-NFI resilient farms (Table 5). In contrast, cows in RROA resilient farms have a lower mean acres per cow and a lower mean percent of crop acres owned when compared to non-RROA resilient farms (Table 6).

The summary statistics in Tables 7-12 show important features of the nutrition factors. These were separated from the other explanatory variables in Tables 5 and 6, as only the nutrition variables change across feed weighting datasets. The nutrition summary statistics were fairly similar across the three feed weighting datasets. For all feed weighting datasets, there are zero observations for cottonseed expenses for NFI resilient farms (Tables 7, 9, and 11), and there are zero observations for both cottonseed and soybean expenses for RROA resilient farms (Tables 8, 10, and 12). The percent roughage was also found to be lower for resilient farms under either of the resiliency measures when compared to non-resilient farms. The expense of corn silage, which is commonly homegrown and fed on most farms, is lower across all feed weighting datasets for NFI resilient farms versus non-NFI resilient farms (Tables 7, 9, and 11). However, corn silage expense is higher for RROA resilient farms when compared to non-RROA resilient farms (Tables 8, 10, and 12). Tables 7-12 have relatively low means for all feed expenses, as all feed variables include observations of zero for feeds that are not fed to cows rather than missing.

Table 5: Summary Statistics for the Dependent and Explanatory Variables Excluding the Nutrition Factors in the NFI Resiliency Models for the EW, PGW, and VW Feed Datasets, Split by All Farms, Farms Considered Resilient by the Adjusted NFI Ratio, and Non-NFI Resilient Farms.[1]

	All Farms			NFI Resilient Farms			Non-NFI Resilient Farms		
Variable	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
NFI Resiliency	96,812	0.12	0.32	11,577	1.00	0.00	85,235	0.00	0.00
Age of Operator	100,045	54.60	10.43	11,577	44.36	9.06	85,235	56.04	9.77
Age of Operator Squared	100,045	3,089.56	1,083.27	11,577	2,050.07	781.99	85,235	3,236.12	1,040.81
Second Generation	100,045	0.82	0.39	11,577	0.82	0.39	85,235	0.82	0.38
Dairy Initiative	99,258	0.18	0.38	11,577	0.64	0.48	84,448	0.12	0.32
Hired Labor per Cow	95,051	45,381.04	29,313.75	11,526	11,176.21	13,389.29	80,619	50,629.84	27,762.71
ECM	85,743	17,540.64	9,334.28	10,112	15,060.65	8,246.82	72,777	17,964.89	9,419.38
Death Rate	100,045	3.61	2.26	11,577	2.90	2.03	85,235	3.66	2.21
Cull Rate	100,045	21.02	8.67	11,577	21.31	10.19	85,235	21.10	8.36
Herd Size	100,045	374.64	299.73	11,577	110.52	58.65	85,235	415.51	303.45
Acres per Cow	97,709	2.60	1.77	9,791	2.95	1.81	84,685	2.54	1.72
Percent Crop Acres Owned	100,045	29.13	31.19	11,577	36.71	35.26	85,235	27.96	30.04
Debt to Asset Ratio	100,045	44.87	27.47	11,577	42.54	26.94	85,235	44.02	25.56
Working Capital per Cow	100,045	1,051.64	1,417.24	11,577	1,600.95	2,822.67	85,235	995.42	1,087.94
Interest Expense per Cow	100,045	199.00	171.24	11,577	141.91	158.84	85,235	207.31	170.26

[1] These values do not change across the different feed weighting datasets.

Table 6: Summary Statistics for the Dependent and Explanatory Variables Excluding the Nutrition Factors in the RROA Resiliency Models for the EW, PGW, and VW Feed Datasets, Split by All Farms, Farms Considered Resilient by the RROA, and Non-RROA Resilient Farms.[1]

		All Farms			RROA Resilient Farms			Non-RROA Resilient Farms	
Variable	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
RROA Resiliency	96,812	0.14	0.35	13,417	1.00	0.00	83,395	0.00	0.00
Age of Operator	100,045	54.60	10.43	13,417	53.43	12.83	83,395	54.84	9.94
Age of Operator Squared	100,045	3,089.56	1,083.27	13,417	3,019.39	1,330.00	83,395	3,106.34	1,038.46
Second Generation	100,045	0.82	0.39	13,417	0.89	0.31	83,395	0.81	0.39
Dairy Initiative	99,258	0.18	0.38	13,417	0.49	0.50	82,608	0.13	0.33
Hired Labor per Cow	95,051	45,381.04	29,313.75	13,366	24,815.77	19,293.10	78,779	49,237.18	29,403.97
ECM	85,743	17,540.64	9,334.28	11,726	16,852.79	9,123.37	71,163	17,735.46	9,360.98
Death Rate	100,045	3.61	2.26	13,417	3.34	1.57	83,395	3.61	2.29
Cull Rate	100,045	21.02	8.67	13,417	20.75	9.04	83,395	21.18	8.52
Herd Size	100,045	374.64	299.73	13,417	278.91	155.89	83,395	395.15	316.51
Acres per Cow	97,709	2.60	1.77	11,922	2.30	0.91	82,554	2.62	1.81
Percent Crop Acres Owned	100,045	29.13	31.19	13,417	21.25	28.95	83,395	30.26	30.96
Debt to Asset Ratio	100,045	44.87	27.47	13,417	31.86	22.40	83,395	45.78	25.71
Working Capital per Cow	100,045	1,051.64	1,417.24	13,417	1,134.07	772.51	83,395	1,057.17	1,504.56
Interest Expense per Cow	100,045	199.00	171.24	13,417	91.12	92.23	83,395	216.92	173.46

[1] These values do not change across the different feed weighting datasets.

Table 7: Summary Statistics for the Explanatory Variables of Nutrition Factors in the NFI Resiliency Models for the EW Dataset, Split by All Farms, NFI Resilient Farms, and Non-NFI Resilient Farms.[1]

EW		All Farms			NFI Resilient Farms			Non-NFI Resilient Farms	
Variable	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
E_PVM_I	100,045	753.43	579.01	11,577	593.05	511.03	85,235	782.68	583.62
E_PVM_III	100,045	793.97	600.17	11,577	615.46	521.22	85,235	826.12	605.78
E_allCorn	100,045	188.59	168.22	11,577	139.99	152.98	85,235	198.91	170.14
E_allCornSilage	100,045	247.46	200.34	11,577	224.74	200.88	85,235	252.95	200.71
E_allHay	100,045	143.58	198.58	11,577	170.27	239.15	85,235	143.67	194.08
E_Cottonseed	92,768	17.96	56.64	10,886	0.00	0.00	78,976	21.09	60.85
E_BeetPulp	93,074	4.66	23.62	10,882	1.82	6.79	79,286	5.22	25.42
E_Oats	93,054	1.59	12.49	10,874	3.51	16.40	79,274	1.02	10.18
E_Pasture	93,255	1.27	10.23	10,879	4.38	13.70	79,470	0.89	9.77
E_allDDGS	100,045	15.43	52.95	11,577	7.96	27.97	85,235	16.47	55.71
E_Barley	93,349	0.38	4.91	10,886	2.46	13.80	79,557	0.11	1.27
E_Soybeans	93,333	1.17	12.30	10,863	3.21	17.80	79,564	0.74	10.28
Percent Roughage Range	88,498	0.55	0.50	9,791	0.45	0.50	75,960	0.56	0.50

[1] Summary statistics for continuous expenses of feedstuffs are reported for all observations.

Table 8: Summary Statistics for the Explanatory Variables of Nutrition Factors in the RROA Resiliency Models for the EW Dataset, Split by All Farms, RROA Resilient Farms, and Non-RROA Resilient Farms.[1]

EW		All Farms			RROA Resilient Farms			Non-RROA Resilient Farms	
Variable	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
E_PVM_I	100,045	753.43	579.01	13,417	871.86	587.33	83,395	742.01	575.27
E_PVM_III	100,045	793.97	600.17	13,417	893.49	594.95	83,395	786.04	599.72
E_allCorn	100,045	188.59	168.22	13,417	178.48	170.39	83,395	194.02	168.99
E_allCornSilage	100,045	247.46	200.34	13,417	266.56	215.18	83,395	246.84	198.41
E_allHay	100,045	143.58	198.58	13,417	83.17	118.14	83,395	157.10	208.61
E_Cottonseed	92,768	17.96	56.64	13,366	7.88	37.15	76,496	20.40	60.11
E_BeetPulp	93,074	4.66	23.62	13,362	1.48	6.17	76,806	5.39	25.81
E_Oats	93,054	1.59	12.49	13,366	0.00	0.00	76,782	1.55	12.06
E_Pasture	93,255	1.27	10.23	13,359	3.45	12.40	76,990	0.94	9.95
E_allDDGS	100,045	15.43	52.95	13,417	6.87	26.12	83,395	16.83	56.27
E_Barley	93,349	0.38	4.91	13,366	2.00	12.49	77,077	0.11	1.29
E_Soybeans	93,333	1.17	12.30	13,366	0.00	0.00	77,061	1.22	12.42
Percent Roughage Range	88,498	0.55	0.50	12,340	0.44	0.50	73,411	0.57	0.50

[1] Summary statistics for continuous expenses of feedstuffs are reported for all observations.

Table 9: Summary Statistics for the Explanatory Variables of Nutrition Factors in the NFI Resiliency Models for the PGW Dataset, Split by All Farms, NFI Resilient Farms, and Non-NFI Resilient Farms.[1]

PGW		All Farms			NFI Resilient Farms			Non-NFI Resilient Farms	
Variable	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
E_PVM_I	100,045	751.11	618.91	11,577	598.15	542.29	85,235	779.25	625.35
E_PVM_III	100,045	791.69	643.28	11,577	620.59	553.95	85,235	822.75	651.05
E_allCorn	100,045	188.42	180.93	11,577	139.85	162.73	85,235	198.73	183.56
E_allCornSilage	100,045	247.46	215.79	11,577	224.74	214.94	85,235	252.94	216.46
E_allHay	100,045	141.57	201.10	11,577	169.17	236.40	85,235	141.47	197.49
E_Cottonseed	92,775	18.00	58.78	10,850	0.00	0.00	79,023	21.14	63.17
E_BeetPulp	92,889	4.67	24.42	10,850	1.83	7.06	79,137	5.23	26.29
E_Oats	92,892	1.60	13.02	10,850	3.52	17.12	79,140	1.02	10.64
E_Pasture	92,966	1.28	10.50	10,850	4.39	14.19	79,214	0.90	10.01
E_allDDGS	100,045	15.43	55.12	11,577	7.96	28.86	85,235	16.47	58.03
E_Barley	93,013	0.38	5.18	10,850	2.47	14.57	79,261	0.11	1.32
E_Soybeans	93,047	1.18	12.68	10,838	3.25	18.48	79,307	0.75	10.53
Percent Roughage Range	88,301	0.55	0.50	9,996	0.45	0.50	75,473	0.56	0.50

[1] Summary statistics for continuous expenses of feedstuffs are reported for all observations.

Table 10: Summary Statistics for the Explanatory Variables of Nutrition Factors in the RROA Resiliency Models for the PGW Dataset, Split by All Farms, RROA Resilient Farms, and Non-RROA Resilient Farms.[1]

PGW	All Farms			RROA Resilient Farms			Non-RROA Resilient Farms		
Variable	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
E_PVM_I	100,045	751.11	618.91	13,417	875.56	638.89	83,395	738.62	613.39
E_PVM_III	100,045	791.69	643.28	13,417	897.19	648.26	83,395	782.71	641.40
E_allCorn	100,045	188.42	180.93	13,417	178.35	182.12	83,395	193.84	182.12
E_allCornSilage	100,045	247.46	215.79	13,417	266.56	231.56	83,395	246.84	213.82
E_allHay	100,045	141.57	201.10	13,417	83.17	123.32	83,395	154.69	211.09
E_Cottonseed	92,775	18.00	58.78	13,345	7.90	38.65	76,528	20.45	62.39
E_BeetPulp	92,889	4.67	24.42	13,345	1.49	6.40	76,642	5.40	26.70
E_Oats	92,892	1.60	13.02	13,345	0.00	0.00	76,645	1.55	12.60
E_Pasture	92,966	1.28	10.50	13,345	3.45	12.83	76,719	0.95	10.20
E_allDDGS	100,045	15.43	55.12	13,417	6.87	26.94	83,395	16.83	58.61
E_Barley	93,013	0.38	5.18	13,345	2.01	13.18	76,766	0.11	1.34
E_Soybeans	93,047	1.18	12.68	13,345	0.00	0.00	76,800	1.23	12.77
Percent Roughage Range	88,301	0.55	0.50	12,473	0.43	0.50	72,996	0.57	0.50

[1] Summary statistics for continuous expenses of feedstuffs are reported for all observations.

Table 11: Summary Statistics for the Explanatory Variables of Nutrition Factors in the NFI Resiliency Models for the VW Dataset, Split by All Farms, NFI Resilient Farms, and Non-NFI Resilient Farms.[1]

VW	All Farms			NFI Resilient Farms			Non-NFI Resilient Farms		
Variable	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
E_PVM_I	100,045	710.61	650.69	11,577	570.56	556.93	85,235	735.50	660.43
E_PVM_III	100,045	751.20	677.63	11,577	593.01	568.38	85,235	779.01	689.20
E_allCorn	100,045	184.46	179.50	11,577	135.10	155.17	85,235	194.73	182.80
E_allCornSilage	100,045	242.27	218.11	11,577	216.37	208.87	85,235	248.03	219.91
E_allHay	100,045	143.60	214.51	11,577	175.45	268.25	85,235	143.00	208.07
E_Cottonseed	99,573	16.79	58.07	11,538	0.00	0.00	84,826	19.71	62.46
E_BeetPulp	99,584	4.36	24.17	11,538	1.72	6.85	84,837	4.89	26.03
E_Oats	99,637	1.49	12.38	11,538	3.31	16.36	84,890	0.95	10.06
E_Pasture	99,642	1.19	10.61	11,536	4.13	13.89	84,897	0.84	10.22
E_allDDGS	100,045	15.42	55.15	11,577	7.96	29.38	85,235	16.45	58.00
E_Barley	99,668	0.36	4.92	11,536	2.32	13.89	84,923	0.10	1.29
E_Soybeans	99,674	1.10	12.43	11,533	3.06	18.85	84,932	0.70	10.33
Percent Roughage Range	78,183	0.55	0.50	8,941	0.45	0.50	66,675	0.56	0.50

[1] Summary statistics for continuous expenses of feedstuffs are reported for all observations.

Table 12: Summary Statistics for the Explanatory Variables of Nutrition Factors in the RROA Resiliency Models for the VW Dataset, Split by All Farms, RROA Resilient Farms, and Non-RROA Resilient Farms.[1]

VW		**All Farms**			**RROA Resilient Farms**			**Non-RROA Resilient Farms**	
Variable	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
E_PVM_I	100,045	710.61	650.69	13,417	839.14	689.32	83,395	695.93	642.57
E_PVM_III	100,045	751.20	677.63	13,417	860.76	699.09	83,395	740.04	673.73
E_allCorn	100,045	184.46	179.50	13,417	175.02	181.87	83,395	189.63	180.50
E_allCornSilage	100,045	242.27	218.11	13,417	257.23	228.62	83,395	242.15	217.17
E_allHay	100,045	143.60	214.51	13,417	83.17	125.41	83,395	157.13	226.00
E_Cottonseed	99,573	16.79	58.07	13,390	7.87	38.74	82,974	18.88	61.46
E_BeetPulp	99,584	4.36	24.17	13,396	1.48	6.39	82,979	4.99	26.31
E_Oats	99,637	1.49	12.38	13,396	0.00	0.00	83,032	1.43	11.87
E_Pasture	99,642	1.19	10.61	13,394	3.44	12.88	83,039	0.88	10.36
E_allDDGS	100,045	15.42	55.15	13,417	6.87	27.43	83,395	16.82	58.59
E_Barley	99,668	0.36	4.92	13,394	2.00	12.91	83,065	0.10	1.31
E_Soybeans	99,674	1.10	12.43	13,396	0.00	0.00	83,069	1.14	12.61
Percent Roughage Range	78,183	0.55	0.50	11,182	0.44	0.50	64,434	0.57	0.50

[1] Summary statistics for continuous expenses of feedstuffs are reported for all observations.

6.2.2 *Analysis of Resiliency Model Results*

Tables 13-15 show the resiliency regression results for the Detailed Feed and Composite Feed Models for each resiliency measure for each feed weighting dataset. When comparing the model results, the Detailed Feed Model and the Composite Feed Model have similar findings to each other within resiliency measures and feed weighting datasets. More differences occur when considering the feed weighting dataset, and the most differences occur when considering the resiliency measure. Because the dependent variables on these regressions are binary variables, the magnitudes of the coefficients are fairly small and are interpreted as the percent change in the likelihood of resiliency. The sign is the most important part of the coefficients on these regressions.

The values for total R-squared and R-squared between were higher for the Detailed Feed Model over the Composite Feed Model for each of the resiliency measures and feed weighting datasets. The values for total R-squared and R-squared between were highest for the models on NFI resiliency across all feed weighting datasets. The NFI resiliency measure had the highest values for total R-squared and R-squared within in the PGW feed dataset, followed by the EW feed dataset and the VW feed dataset. VW likely had the lowest R-squared values for NFI resiliency because it had the fewest number of observations due to more outliers being identified from its individual feed allocation.

6.2.2.1 Human Resources

The human resource factors, including *age of operator, age of operator squared, second generation, dairy initiative,* and *hired labor per cow*, had similar signs across all feed weighting datasets. *Age of operator* had a negative impact on resiliency measured by

adjusted NFI ratio and RROA. As the primary operator gains an additional year of age, the likelihood of resiliency decreased within the range of 0.268% to 5.24%, when considering significance at the 5% level. Depending on the resiliency measure, *age of operator squared* had different signs. *Age of operator squared* was found to be negative for the Detailed Feed Model on NFI resiliency; however, it was positive for the Composite Feed Model on NFI resiliency and both the Detailed and Composite Feed Models for RROA resiliency. The opposite signs between *age of operator* (negative) and *age of operator squared* (positive) suggest that the likelihood of resiliency decreases at an increasing rate as farmers gain age. For NFI resiliency, *age of operator squared* was only significant at the 1% level for the Detailed Feed Model for the PGW feed dataset and was significant at the 5% level for both the Detailed Feed and Composite Feed Models for the EW and VW feed datasets.

When considering significance at the 1% level, *second generation* had a negative impact on resiliency. The second generation also working on the farm decreased the likelihood of resiliency within the range of 0.111% to 0.668%. As discussed earlier, this is likely because having the second generation also working on the farm means splitting income between two households, reducing overall returns to the farm.

Dairy initiative had the strongest impact on resiliency out of all of the explanatory variables analyzed across all datasets. Participating in the Minnesota Dairy Initiatives Program increased the likelihood of resiliency between 28.7% and 38.5%. As a proxy variable for overall dairy education by Minnesota dairy farmers, the sign and magnitude on *dairy initiative* indicates that farmers who are more likely to educate themselves on how to become more efficient producers are more likely to be resilient.

The final human resources factor, *hired labor per cow*, was significant for all coefficients at the 1% level and was negative across all coefficients. As hired labor increased by an additional dollar per cow, the likelihood of resiliency decreased between 0.000223% and 0.000683%. Although the magnitude was small, this falls in line with expectations of hired labor per cow increasing costs, decreasing profits back to the farm and decreasing the likelihood of resiliency.

6.2.2.2 Animal Health

The animal health measures were fairly similar across the feed weighting datasets; however, they had significant differences between resiliency measures. *ECM* had a relatively small magnitude across all coefficients. *ECM* was statistically significant at the 1% level for RROA resiliency, but it showed inconsistency in significance for NFI resiliency. The majority of significant values for *ECM* were negative. This model did not perfectly capture *ECM*, making it difficult to draw any main conclusions. *ECM* being negative when statistically significant along with its inconsistencies in significance across models could mean that a lower milk yield along with higher concentrations of milk components are the key, rather than standardizing milk yield to a component level.

Death rate was positive for RROA resiliency, while it was negative for NFI resiliency. Increasing death rate by an additional percentage point decreased the likelihood of NFI resiliency within the range of 1.68% to 1.85%. Surprisingly, increasing death rate by an additional percentage point increased the likelihood of RROA resiliency within the range of 0.946% to 1.91%. The NFI resiliency models made the most sense for

death rate, as a lower number of dead cows means fewer animal health issues and better overall health of the herd.

When statistically significant at the 5% level, *cull rate* had a positive impact on resiliency. *Cull rate* was statistically significant for NFI resiliency at the 1% level, while there were inconsistencies among significance for RROA resiliency. For the significant values, an additional percentage point increase in cull rate increased the likelihood of resiliency within the range of 0.117% to 0.201%. A positive impact of cull rate on resiliency likely occurred because farmers are making better decisions of which cows to cull and replace with more profitable cows. In these datasets, the average cull rate is relatively low, making this a viable reason.

6.2.2.3 Herd Structure

The herd structure category had the least consistency across the resiliency measures. *Herd size* was statistically significant at the 1% level for all models, resiliency measures, and datasets. *Herd size* had a negative impact on NFI resiliency but had a positive impact on RROA resiliency. *Acres per cow* also had inconsistent findings across models. *Acres per cow* was negative for NFI resiliency. For RROA resiliency, *acres per cow* was positive for the Detailed Feed Model for all datasets and negative for the Composite Feed Model for the PGW and VW feed datasets (not significant at the 5% level for EW). *Percent crop acres owned* was positive for RROA resiliency but was not statistically significant at the 5% level for any models for NFI resiliency. An additional percentage point increase in the percent of crop acres owned increased the likelihood of RROA resiliency between 0.0551% and 0.125%. Although the magnitude was small, the

positive sign was consistent with our expectations, as a higher percentage of crop acres owned out of all crop acres operated could lead to higher assets (owned versus leased) or lower liabilities (owned versus loans) and thus improved long-term profitability.

6.2.2.4 Financials

The financial indicators were very consistent within each resiliency measure but differed in signs across the resiliency measures. *Debt to asset ratio* was positive for NFI resiliency. A 0.01-point increase in debt to asset ratio increased the likelihood of NFI resiliency between 0.300% and 0.315%. A positive coefficient on *debt to asset ratio* makes sense, as it could indicate a lender's trust of resilient farms, rather than a warning of financial concern. *Debt to asset ratio* was negative for RROA resiliency, as a 0.01-point increase in debt to asset ratio decreases the likelihood of RROA resiliency between 0.288% and 0.369%. A negative coefficient on *debt to asset ratio* could indicate that high debt and low solvency is a concern.

Working capital per cow, a measure of liquidity, was positive for NFI resiliency and negative for RROA resiliency. An additional dollar per cow of working capital increased the likelihood of NFI resiliency within the range of 0.00287% and 0.00366%, while decreasing the likelihood of RROA resiliency between 0.00359% and 0.00429%. A reason for the coefficient of *working capital per cow* for NFI resiliency being positive while RROA resiliency was negative could be because of working capital's direct influence on NFI, rather than RROA. It is likely that a cow with a high NFI also has a high working capital.

The last financial indicator used in these models was *interest expense per cow*.

Interest expense per cow was found to be negative across both resiliency measures. An additional dollar per cow in interest expense decreased the likelihood of resiliency within the range of 0.0304% and 0.0622%. This was expected, as a higher interest expense leads to higher costs and lower profitability.

6.2.2.5 Nutrition

There were several differences in the coefficients on the nutrition factors, depending on the resiliency measure and feed dataset used. The PGW and VW feed datasets had the same signs on their coefficients (except for corn silage) and differed from the EW dataset for the signs on cottonseed expense and DDGS expense for RROA resiliency. The coefficient on corn silage expense was negative for PGW but positive for the EW and VW feed datasets for RROA resiliency. These inconsistencies across the feed weighting datasets only occurred for RROA resiliency and did not appear for NFI resiliency.

Inconsistencies with signs and magnitudes between resiliency measures also existed. The nutrition factors that stayed consistent in signs across resiliency measures were corn silage expense for EW and VW (positive), beet pulp expense (negative), pasture expense (negative), and barley expense (positive). The remaining nutrition variables, including expenses for the "protein, vitamins, and minerals" variables, corn, hay, cottonseed, oats, DDGS, and soybeans, and *percent roughage range*, were all inconsistent in signs across the two resiliency measures.

For NFI resiliency, expenses for "protein, vitamins, and minerals", corn, cottonseed, and pasture as well as *percent roughage range* showed negative impacts on resiliency, while expenses for corn silage, hay, oats, DDGS, barley, and soybeans showed positive impacts on resiliency. As roughages, corn silage and hay are relatively cheaper feeds, resulting in a higher net farm income year-over-year when fed. Spending an additional dollar per cow per year on corn silage increased the likelihood of NFI resiliency within the range of 0.0356% and 0.0567%. Corn silage, commonly homegrown, can be less expensive for farmers while still allowing for increased milk yield and component levels because of its high energy content. Similarly, spending an additional dollar per cow per year on hay increased the likelihood of NFI resiliency by a range of 0.0237% to 0.0302%. Although the magnitudes were relatively low for the feed variables in this analysis, spending one additional dollar per cow per year on a feedstuff is not a large investment and the likelihood of resiliency increases more as more money is spent on these feedstuffs.

Percent roughage range surprisingly had a negative impact on NFI resiliency, while RROA resiliency had a positive sign for *percent roughage range*. Feeding a percent roughage of dietary DM within the optimal range of 40-60% decreased the likelihood of NFI resiliency between 9.55% and 11.5% but increased the likelihood of RROA resiliency between 3.36% and 6.48%. The large magnitude and negative sign for the NFI resiliency regressions was surprising as scientific research highlights the importance of feeding roughage within the optimal range. Of the cows in the dataset, approximately 55% of them had a percent roughage within the optimal range, and the average percent roughage fed to cows was approximately 44%. When analyzing the

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remaining 45% of cows that do not consume an optimal percent roughage, the majority of these cows had a percent roughage lower than 40%. Although this could mean that the higher level of concentrates is increasing revenue, the associated costs would be expected to be too high and outweigh this increased revenue. It is possible that not all feeds were reported in the dataset for both quantities and expenses, especially those forages that are homegrown or grazing pasture, causing this percent roughage to be lower, on average, than expected.

Table 13: Between-Effects Model Results Using NFI Resiliency and RROA Resiliency as Dependent Variables for the EW Feed Dataset across Two Levels of Feed Detail.

	NFI Resiliency		RROA Resiliency	
Explanatory Variable	**Detailed Feed**	**Composite Feed**	**Detailed Feed**	**Composite Feed**
Age of Operator	-0.00284*	-0.00810**	-0.0494**	-0.0523**
	(0.00111)	(0.00111)	(0.00133)	(0.00135)
Age of Operator Squared	-0.0000227*	-0.0000261*	0.000513**	0.000538**
	(0.0000106)	(0.0000106)	(0.0000127)	(0.0000129)
Second Generation	-0.00157	0.00273	-0.0530**	-0.0477**
	(0.00461)	(0.00431)	(0.00553)	(0.00524)
Dairy Initiative	0.286**	0.293**	0.376**	0.364**
	(0.00392)	(0.00389)	(0.00471)	(0.00473)
Hired Labor per Cow	-0.00000238**	-0.00000223**	-0.00000683**	-0.00000589**
	(0.0000000754)	(0.0000000719)	(0.0000000905)	(0.0000000875)
ECM	-0.000000325	-0.000000383	-0.00000428**	-0.00000452**
	(0.0000000254)	(0.0000000257)	(0.000000305)	(0.000000313)
Death Rate	-0.0182**	-0.0180**	0.0118**	0.00946**
	(0.000760)	(0.000748)	(0.000913)	(0.000910)
Cull Rate	0.00141**	0.00149**	0.00117**	0.00121**
	(0.000222)	(0.000222)	(0.000266)	(0.000268)
Herd Size	-0.000135**	-0.000140**	0.000434**	0.000343**
	(0.00000986)	(0.00000985)	(0.0000118)	(0.0000120)
Acres per Cow	-0.0108**	-0.0131**	0.0213**	0.00116
	(0.00123)	(0.00114)	(0.00148)	(0.00139)
Percent Crop Acres Owned	-0.0000920	-0.0000144	0.00125**	0.000734**
	(0.0000566)	(0.0000550)	(0.0000680)	(0.0000669)
Debt to Asset Ratio	0.00307**	0.00300**	-0.00288**	-0.00323**
	(0.0000932)	(0.0000931)	(0.000112)	(0.000113)
Working Capital per Cow	0.0000301**	0.0000366**	-0.0000429**	-0.0000401**
	(0.00000128)	(0.00000124)	(0.00000153)	(0.00000151)
Interest Expense per Cow	-0.000574**	-0.000563**	-0.000542**	-0.000383***
	(0.0000138)	(0.0000136)	(0.0000166)	(0.0000166)

E_PVM_I	-0.000116** (0.00000485)		0.000141** (0.00000582)	
E_PVM_III		-0.000138** (0.00000484)		0.000106** (0.00000588)
E_allCorn	-0.000523** (0.0000153)	-0.000450** (0.0000152)	0.000000707 (0.0000184)	0.0000643** (0.0000185)
E_allCornSilage	0.000463** (0.0000151)	0.000495** (0.0000153)	0.0000355 (0.0000181)	0.0000930** (0.0000187)
E_allHay	0.000274** (0.00000950)	0.000237** (0.00000880)	-0.000434** (0.0000114)	-0.000381** (0.0000107)
E_Cottonseed	-0.000335** (0.0000350)		-0.000929** (0.0000421)	
E_BeetPulp	-0.000114 (0.0000794)		-0.000497** (0.0000953)	
E_Oats	0.00115** (0.000187)		-0.00270** (0.000225)	
E_Pasture	-0.00191** (0.000168)		-0.00304** (0.000201)	
E_allDDGS	0.000730** (0.0000367)		0.000391** (0.0000441)	
E_Barley	0.00954** (0.000295)		0.00987** (0.000355)	
E_Soybeans	0.000927** (0.000348)		-0.00353** (0.000166)	
Percent Roughage Range	-0.110** (0.00348)	-0.104** (0.00344)	0.0619** (0.00418)	0.0648** (0.00419)
Observations (Total)	66,995	67,875	66,995	67,875
Observations (Groups)	31,657	31,809	31,657	31,809
R-squared (Between)	0.532	0.502	0.456	0.405
R-squared (Total)	0.461	0.443	0.399	0.367

Note: The quantities below the estimates are the standard errors.

*=Significant at the 5% level, **=Significant at the 1% level

Table 14: Between-Effects Model Results Using NFI Resiliency and RROA Resiliency as Dependent Variables for the PGW Feed Dataset across Two Levels of Feed Detail.

Explanatory Variable	NFI Resiliency		RROA Resiliency	
	Detailed Feed	**Composite Feed**	**Detailed Feed**	**Composite Feed**
Age of Operator	-0.000538	-0.00543**	-0.0489**	-0.0515**
	(0.00108)	(0.00108)	(0.00134)	(0.00136)
Age of Operator Squared	-0.0000414**	0.00000544	0.000507**	0.000529**
	(0.0000103)	(0.0000103)	(0.0000127)	(0.0000129)
Second Generation	-0.0111*	-0.00245	-0.0592**	-0.0530**
	(0.00444)	(0.00418)	(0.00550)	(0.00524)
Dairy Initiative	0.296**	0.303**	0.378**	0.369**
	(0.00381)	(0.00378)	(0.00472)	(0.00474)
Hired Labor per Cow	-0.00000252**	-0.00000233**	-0.00000664**	-0.00000582**
	(0.0000000733)	(0.0000000702)	(0.0000000909)	(0.000000088)
ECM	-0.000000246	0.000000416	-0.00000557**	-0.00000596**
	(0.000000270)	(0.000000274)	(0.000000335)	(0.000000343)
Death Rate	-0.0185**	-0.0180**	0.0163**	0.0139**
	(0.000736)	(0.000730)	(0.000912)	(0.000915)
Cull Rate	0.00157**	0.00194**	-0.000173	0.000494
	(0.000210)	(0.000212)	(0.000261)	(0.000266)
Herd Size	-0.000148**	-0.000158**	0.000437**	0.000358**
	(0.00000957)	(0.00000957)	(0.0000119)	(0.0000120)
Acres per Cow	-0.00758**	-0.0121**	0.0133**	-0.00452**
	(0.00118)	(0.00110)	(0.00147)	(0.00138)
Percent Crop Acres Owned	-0.0000215	0.0000227	0.00107**	0.000606**
	(0.0000547)	(0.0000532)	(0.0000678)	(0.0000667)
Debt to Asset Ratio	0.00307**	0.00303**	-0.00325**	-0.00353**
	(0.0000899)	(0.0000905)	(0.000111)	(0.000113)
Working Capital per Cow	0.0000287**	0.0000365**	-0.0000375**	-0.0000362**
	(0.00000125)	(0.00000121)	(0.00000154)	(0.00000152)
Interest Expense per Cow	-0.000620**	-0.000595**	-0.000490**	-0.000340**
	(0.0000134)	(0.0000133)	(0.0000167)	(0.0000167)

E_PVM_I	-0.000127** (0.00000492)		0.000148** (0.00000610)	
E_PVM_III		-0.000148** (0.00000488)		0.000115** (0.00000611)
E_allCorn	-0.000589** (0.0000153)	-0.000505** (0.0000152)	0.0000237 (0.0000190)	0.000113** (0.0000190)
E_allCornSilage	0.000530** (0.0000147)	0.000567** (0.0000149)	-0.0000377* (0.0000182)	0.0000191 (0.0000186)
E_allHay	0.000302** (0.00000955)	0.000261** (0.00000875)	-0.000392** (0.0000118)	-0.000348** (0.0000110)
E_Cottonseed	-0.000348** (0.0000336)		0.000923** (0.0000417)	
E_BeetPulp	-0.000198** (0.0000755)		-0.000577** (0.0000935)	
E_Oats	0.000459* (0.000183)		-0.00221** (0.000227)	
E_Pasture	-0.00210** (0.000164)		-0.00300** (0.000203)	
E_allDDGS	0.000701** (0.0000338)		-0.000472** (0.0000419)	
E_Barley	0.00904** (0.000281)		0.00970** (0.000348)	
E_Soybeans	0.000857** (0.000133)		-0.00358** (0.000165)	
Percent Roughage Range	-0.115** (0.00338)	-0.104** (0.00336)	0.0412** (0.00419)	0.0472** (0.00421)
Observations (Total)	68,878	69,478	68,878	69,478
Observations (Groups)	32,331	32,477	32,331	32,477
R-squared (Between)	0.544	0.514	0.444	0.395
R-squared (Total)	0.463	0.446	0.376	0.356

Note: The quantities below the estimates are the standard errors.

*=Significant at the 5% level, **=Significant at the 1% level

Table 15: Between-Effects Model Results Using NFI Resiliency and RROA Resiliency as Dependent Variables for the VW Feed Dataset across Two Levels of Feed Detail.

	NFI Resiliency		RROA Resiliency	
Explanatory Variable	**Detailed Feed**	**Composite Feed**	**Detailed Feed**	**Composite Feed**
Age of Operator	-0.00268*	-0.00737**	-0.0505**	-0.0524**
	(0.00111)	(0.00111)	(0.00136)	(0.00137)
Age of Operator Squared	-0.0000223*	0.0000232*	0.000522**	0.000541**
	(0.0000105)	(0.0000105)	(0.0000129)	(0.0000130)
Second Generation	-0.0167**	-0.00264	-0.0668**	-0.0652**
	(0.00455)	(0.00427)	(0.00558)	(0.00528)
Dairy Initiative	0.287**	0.295**	0.385**	0.379**
	(0.00391)	(0.00388)	(0.00480)	(0.00480)
Hired Labor per Cow	-0.00000245**	-0.00000245**	-0.00000632**	-0.00000571**
	(0.0000000739)	(0.0000000714)	(0.0000000907)	(0.0000000883)
ECM	-0.00000118**	-0.000000698*	-0.00000797**	-0.00000859**
	(0.000000305)	(0.000000308)	(0.000000374)	(0.000000380)
Death Rate	-0.0168**	-0.0177**	0.0191**	0.0159**
	(0.000746)	(0.000741)	(0.000915)	(0.000917)
Cull Rate	0.00130**	0.00201**	-0.0000202	0.000622*
	(0.000213)	(0.000216)	(0.000262)	(0.000267)
Herd Size	-0.000109**	-0.000107**	0.000386**	0.000323**
	(0.00000954)	(0.00000958)	(0.0000117)	(0.0000118)
Acres per Cow	-0.00779**	-0.0104**	0.00947**	-0.00577**
	(0.00120)	(0.00112)	(0.00147)	(0.00139)
Percent Crop Acres Owned	-0.0000184	0.0000962	0.000887**	0.000551**
	(0.0000551)	(0.0000541)	(0.0000676)	(0.0000669)
Debt to Asset Ratio	0.00315**	0.00315**	-0.00343**	-0.00369**
	(0.0000911)	(0.0000920)	(0.000112)	(0.000114)
Working Capital per Cow	0.0000294**	0.0000359**	-0.0000359**	-0.0000375**
	(0.00000125)	(0.00000123)	(0.00000154)	(0.00000152)
Interest Expense per Cow	-0.000622**	-0.000610**	-0.000433**	-0.000304**
	(0.0000136)	(0.0000135)	(0.0000167)	(0.0000167)

E_PVM_I	-0.0000752** (0.00000455)		0.000126** (0.00000558)	
E_PVM_III		-0.0000951** (0.00000452)		0.000107** (0.00000558)
E_allCorn	-0.000479** (0.0000141)	-0.000409** (0.0000139)	0.000133** (0.0000172)	0.000201** (0.0000172)
E_allCornSilage	0.000356** (0.0000141)	0.000393** (0.0000142)	0.000122** (0.0000172)	0.000155** (0.0000176)
E_allHay	0.000296** (0.00000884)	0.000258** (0.00000798)	-0.000385** (0.0000108)	-0.000354** (0.00000987)
E_Cottonseed	-0.000331** (0.0000304)		0.000827** (0.0000373)	
E_BeetPulp	-0.000224** (0.0000687)		-0.000521** (0.0000843)	
E_Oats	0.000449** (0.000159)		-0.00216** (0.000195)	
E_Pasture	-0.00208** (0.000148)		-0.00256** (0.000181)	
E_allDDGS	0.000535** (0.0000295)		-0.000437** (0.0000362)	
E_Barley	0.00970** (0.000287)		0.00892** (0.000352)	
E_Soybeans	0.00104** (0.000126)		-0.00325** (0.000155)	
Percent Roughage Range	-0.112** (0.00346)	-0.0955** (0.00343)	0.0336** (0.00424)	0.0425** (0.00424)
Observations (Total)	69,254	69,494	69,254	69,494
Observations (Groups)	32,049	32,090	32,049	32,090
R-squared (Between)	0.525	0.498	0.444	0.402
R-squared (Total)	0.451	0.438	0.380	0.361

Note: The quantities below the estimates are the standard errors.
*=Significant at the 5% level, **=Significant at the 1% level

Chapter 7

Discussion

This study analyzed the impacts of the feeding decision and cow nutrition on milk levels, as measured by ECM, and on dairy farm resiliency, as measured by adjusted NFI ratio and RROA. An important piece of this study was converting lactation-level DHIA data to the calendar year to match financials from FINBIN. Matching feed consumption quantities and expenses directly to milk production is essential in creating accurate analysis of the feeding decision's impact on both ECM and resiliency. Without being converted to an annual basis, the cow-level DHIA data is assumed to be balanced from year-to-year, which is not the case considering the volatility of feed costs along with the feedstuffs' associated impacts on milk production.

In the first stage of analyzing the feeding decision, ECM was used as the dependent variable to account for milk fat and protein levels to reflect how a farmer is paid for his/her milk. ECM should be prioritized over milk yield when considering benchmarks for Minnesota dairy farm production. Analysis of the ECM regressions proved corn silage and corn, as continuous variables in the regressions, have positive impacts on ECM on a per unit basis. Corn silage and corn had the highest positive magnitudes of the continuous variables across the feed weighting datasets, confirming our expectations that these commonly fed high energy feeds are important in maximizing ECM production. In addition to corn silage and corn, soybeans are important in balancing protein levels in diets, improving ECM. Feeding the optimal percent roughage of dietary dry matter can result in healthier, more productive cows, as the percent roughage variable

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had a high positive impact on ECM. With low observations in the datasets, oats and barley were not statistically significant in our regressions, making it difficult to estimate their impacts on ECM.

Analysis of the resiliency models showed similar signs and magnitudes for the explanatory variables included by Roberts (2019). Including the nutrition variables in these models did not cause major differences in the model results. The nutrition variables enabled certain characteristics of the feeding decision to be analyzed against resiliency.

Comparing the models for level of feed detail, feed allocation method, and resiliency measure shows several important findings. This research study along with Roberts' (2019) study validates that allocating feed and expense data equally across cows using the EW method is not appropriate given the nature of cows' production, feed consumption, and accumulated costs. Both the PGW and VW feed allocation methods should be considered when allocating feed quantities and expenses to cows over a specified time period rather than the EW method. This research also finds that resiliency measured by the adjusted NFI ratio indicator is the most appropriate over the RROA resiliency indicator when considering long-term profitability. The NFI resiliency indicator is able to measure the profitability from year to year while using a multi-year variable that measures across time. NFI resiliency is a strong measure of profitability over time, as total revenue (denominator of the adjusted NFI ratio) changes more from year to year than total assets (denominator of the RROA) making it easier to analyze how management decisions can change profitability over time. The NFI resiliency models had the most logical coefficients on explanatory variables and had the highest R-squared values, proving that these models explain the greatest variation in resiliency (Tables 13-

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15). The Detailed Feed Model was expected to be superior to the Composite Feed Model, as it captured the specific feeds' impacts on resiliency. Although feeds may be confounded in the dataset, the Detailed Feed Model could potentially distinguish the specific nutrition management conditions that relate highest to resiliency in order to make well informed decisions on the economics of the feeding decision. However, there were no major differences in the signs and magnitudes of the feed variables included in the Composite Feed Model, making the Composite Feed Model more accurate without the detailed level of feed.

The Composite Feed Model using the PGW feed dataset on NFI resiliency is the most impactful for understanding the economics of the feeding decision. Important findings from this regression include the positive impacts of total expenses of corn silage and hay on resiliency. With the large number of observations for these variables, we are confident that these are important to resiliency. The Detailed Feed Model would be preferred if there were more observations of the detailed feedstuffs. Of the feed expense variables with fewer observations in the Detailed Feed Model, such as barley and oats, it is difficult to assume that these findings are accurate with positive impacts on NFI resiliency. Pasture, for example, has a low number of observations in the dataset. Pasture is one of the most difficult feeds to measure consumption for, making our findings of pasture negatively influencing resiliency to be uncertain.

Jointly considering our models on ECM and NFI resiliency concludes that corn silage is one of the most important feedstuffs on Minnesota dairy farms. Corn silage had a positive impact on ECM as well as resiliency measured by the adjusted NFI ratio. Corn silage being commonly homegrown while high in energy has important implications to a

farm's profitability. This research also shows that feed expenses are incredibly important when considering long-term profitability. Although *acres per cow* had inconsistent findings, our feed expense variables proved that commonly homegrown feeds are more likely to result in dairy farm resiliency, as corn silage and hay, the majority of which is made up of alfalfa hay (commonly homegrown on Minnesota dairy farms), had positive coefficients on NFI resiliency. The quantities and adoption of feeds utilized in dairy cattle rations should always be adjusted and balanced based on current feed prices and expenses.

7.1   Cumulative Lifetime Breakeven Analysis

Roberts (2019) included the percentage of cows that breakeven in their first, second, and third lactations as three variables in her resiliency models. This was considered in this study; however, non-consecutive farm data as well as incomplete data for first and second lactations for older cows made estimating breakeven to be difficult without large assumptions. In order to preserve the integrity of the data while still aiming to understand key differences between resilient and non-resilient farms, breakeven analysis was completed for only cows with accurate consecutive revenue and cost data for at least their first and second lactations. This was done using a similar method to Roberts (2019), but fewer assumptions were made as cows who were missing data for their first or second lactation were not included in the analysis.

The breakeven for each cow was calculated as a cumulative lifetime breakeven, meaning that all costs and revenues from each cow throughout her lifetime were included in the breakeven analysis, rather than a single year. Because of the data available for this

research, lifetime breakeven analysis was completed by calculating all costs and revenues of the cows in the dataset to look at the cows' lifetime profits. This cumulative lifetime breakeven included heifer raising costs, lactation costs, and lactation revenues. Heifer raising costs were created by Roberts (2019) using the slide rule developed by Tranel (2019). Lactation costs were created using the expense allocation methods described in the *Data* chapter of this study. Lactation revenues included revenues from milk sales, bull calf sales, and cull sales.

The percentage of cows that breakeven in their first, second, and third lactations were analyzed for 67 of the 82 farms in the dataset. Approximately 51,000 annual cow observations, or a little over half of the total observations in the dataset, were considered in the analysis.[12] Because there were fewer observations for each year and the cow observations that had complete data were not consistent across all years, the percentage of cows that breakeven in their first, second, and third lactations were considered across the seven years of data. Thus, approximately 15,000 unique cow observations were analyzed for each dataset.[13]

Figures 2, 3, and 4 show the percentage of cows that breakeven in the first, second, and third lactations. This data is averaged across all farms and also presented for the subsamples of NFI resilient farms and non-NFI resilient farms. Only NFI resiliency is shown in these figures as this was found to be the best way to measure financial resiliency.

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[12] There were 51,243 observations in the EW dataset, 51,203 observations in the PGW dataset, and 50,918 observations in the VW dataset.
[13] There were 15,061 unique cow observations in the EW dataset, 15,056 unique cow observations in the PGW dataset, and 14,955 unique cow observations in the VW dataset.

Each of the datasets are relatively consistent with each other. The percentage of cows that breakeven in their first lactation is lower for NFI resilient farms (7.3 - 8.3%) than non-NFI resilient farms (12.9 - 14.9%), showing that NFI resilient farms do not necessarily have the earliest breakeven time period for their cows. However, NFI resilient farms have a much higher percentage of cows that breakeven in their second lactation than non-NFI resilient farms (30.3 - 32.7% versus 20.1 - 24.1%). Lastly, NFI resilient farms see a slightly higher percentage of cows who breakeven in their third lactation compared to non-NFI resilient farms (14.2 - 15.1% versus 12.2 - 14.1%).

The biggest takeaway from Figures 2, 3, and 4 is that NFI resilient farms have more cows that breakeven than non-NFI resilient farms. The EW dataset shows the biggest difference in cows who breakeven for NFI resilient farms (54.5%) compared to non-NFI resilient farms (45.9%), followed by the PGW dataset (52.8% versus 48.6%), and the VW dataset (55.1% versus 51.0%). NFI resilient farms are keeping their cows for a longer period of time, allowing them to hit their breakeven and generate a larger amount of lifetime profit at the cow level and overall farm profit for the herd. Although there are fewer cows in NFI resilient herds that are achieving their breakeven in their first lactation when compared to non-NFI resilient herds, cows in NFI resilient herds are more likely to achieve their breakeven at some point in the herd. Non-NFI resilient farms experience a lower percentage of cows achieving their breakeven, resulting in less profitability back to the farm when a cow is not paying her way in the herd.
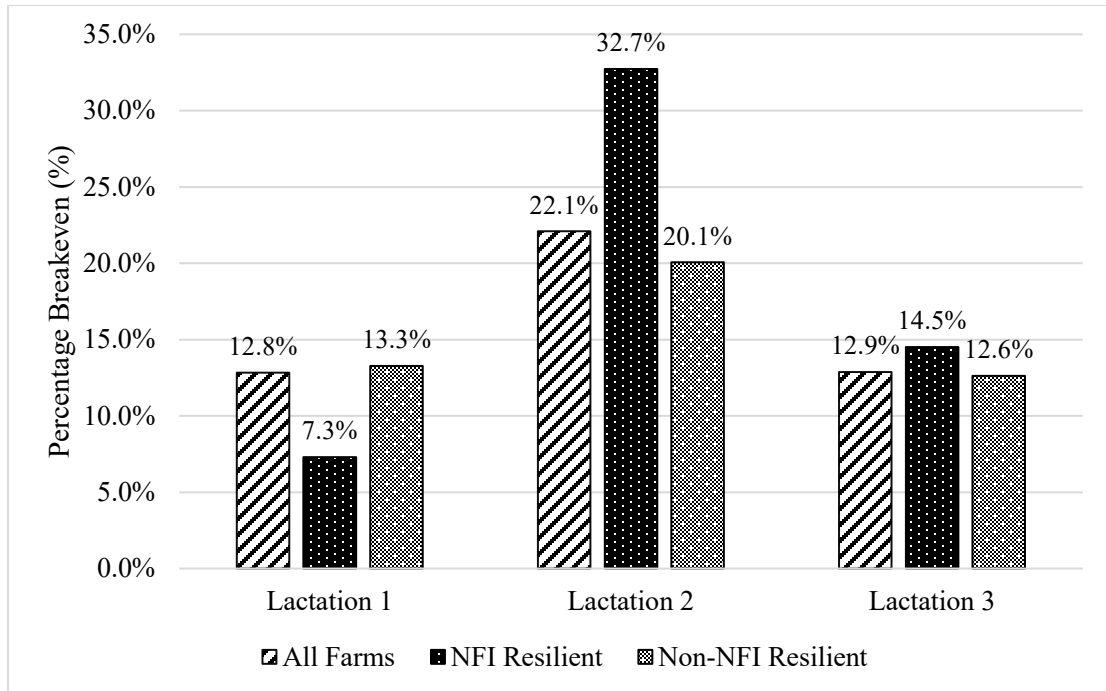
Figure 2: The Percentage of Cows that Breakeven in their First, Second, and Third Lactations in the EW Dataset, Split by All Farms, NFI Resilient Farms, and Non-NFI Resilient Farms.
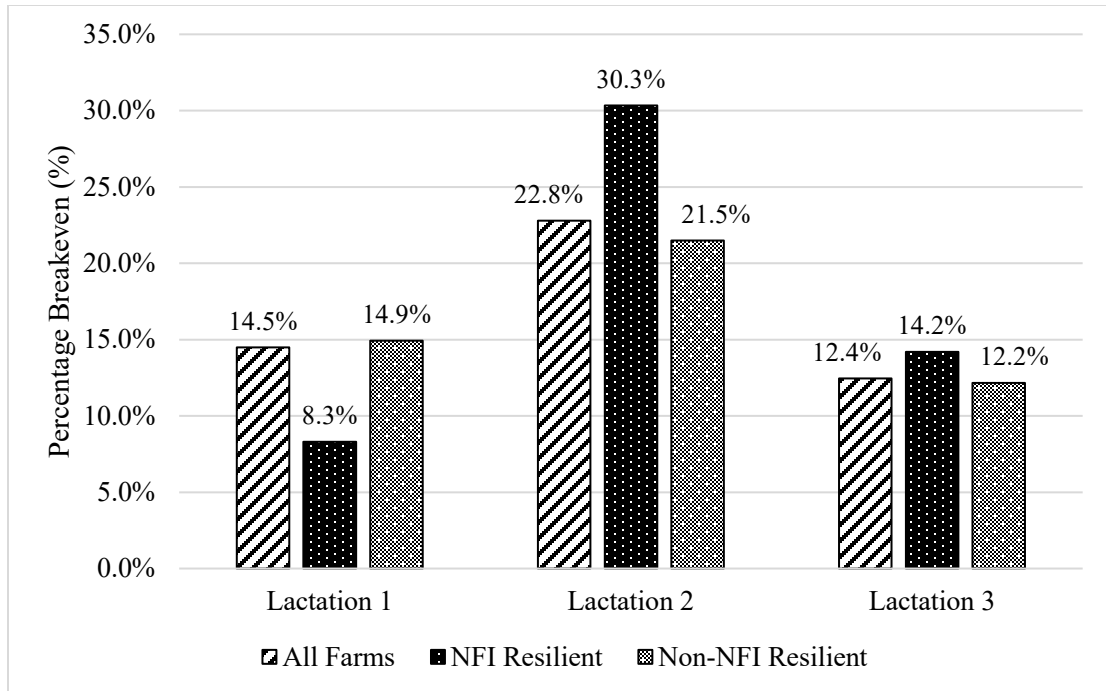
Figure 3: The Percentage of Cows that Breakeven in their First, Second, and Third

Lactations in the PGW Dataset, Split by All Farms, NFI Resilient Farms, and Non-NFI
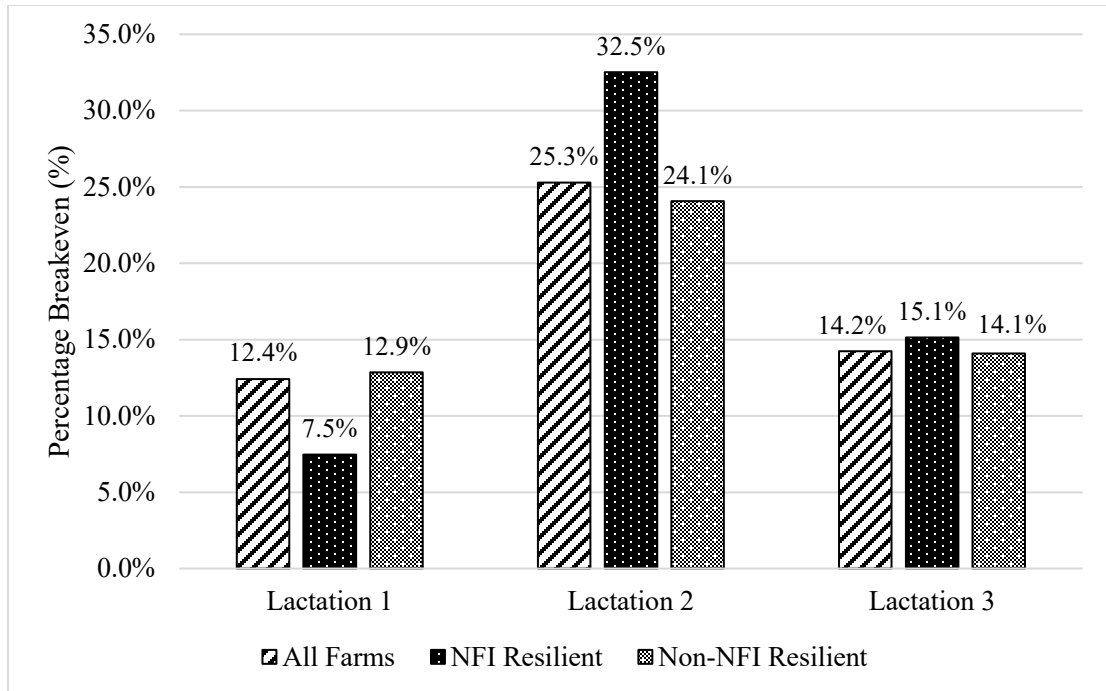
Resilient Farms.

Figure 4: The Percentage of Cows that Breakeven in their First, Second, and Third

Lactations in the VW Dataset, Split by All Farms, NFI Resilient Farms, and Non-NFI

Resilient Farms.

7.2   **Suggestions for Future Research**

Assumptions were made in this analysis that limited our ability to measure nutrition's impact on ECM and farm resiliency perfectly. Yearly feed data was reported in FINBIN, rather than monthly data, which prevented us from understanding the specific rations that were used on farms at a specific time. Monthly FINBIN data for financials and feeds would be more appropriate to match the DHIA data that is composed of monthly tests. Balancing rations is key when understanding the feeding decision; however, only yearly feed quantities and expenses were collected. Actual rations for each year or each pen of each farm would allow for greater detail in analyzing the feeding decision, but this is not feasible given the size of this dataset and the information received from FINBIN. Feed quality is also difficult to measure without data of specific rations, which could result in inaccurate analysis of the feeding decision's impact on ECM. With both ration and feed quality information, these results could have greater accuracy and implications to Minnesota dairy farmers. More detailed ration data along with more cows and a longer time series could improve the results found in the ECM regressions and resiliency models.

The three feed allocation methods – EW, PGW, and VW – allocate feed consumption quantities and expenses to the cow-level, but various assumptions make it impossible to measure feed intake perfectly, as intakes can differ between cows and management systems. The EW method has proven to be inappropriate in allocating expenses and feed consumption to cows. The PGW and VW feed allocation methods are more accurate than EW; however, they do not measure feed intake and expenses perfectly. For example, feed shrink, daily cow health, and stage of lactation are not

considered in allocating the feed consumption, which could cause differences in feed intakes over time. More accurate measurements of cow-level feed intakes and expenses could result in more accurate results for feedstuffs' impacts on ECM and financial resiliency.

Finally, the feed variables from FINBIN show that a more detailed reporting of feeds could aid in finding meaningful implications to dairy farmers. Sixty-three feedstuffs are reported in FINBIN, but not all feeds are reported in great detail to find accurate results for this research. Several feedstuffs reported in FINBIN are likely reported in different categories by different farms. "Protein, vitamins, and minerals" and "complete ration" likely contain feedstuffs that could be specified in individual categories. For example, feedstuffs like soybeans and corn are reported by one farmer as these individual feedstuffs, while another farmer can report them as "protein, vitamins, and minerals" or "complete ration". Because of the inconsistencies in reporting, the more detailed feed models (ECM Regression I and the Detailed Feed Model for the resiliency regressions) are likely inaccurate for the variables that could be reported in different categories. Further research using FINBIN would benefit from a more accurate reporting of feeds and expenses on a monthly basis.

Chapter 8

Conclusion

Volatile and fluctuating market conditions over the past several years have caused deep concern among dairy farmers. Long-term profitability and resiliency have become key to remaining in the dairy business, as margins have become smaller and smaller. Dairy farmers are seeking answers for how to become more efficient and economical producers given the current circumstances of the market. As feed costs are the largest costs on dairy farms, nutrition is an important aspect to analyze for its direct impacts on milk, fat, and protein production, as well as animal health.

Financial resiliency measured by the adjusted NFI ratio proved to be the most effective way to measure long-term profitability. Farm resiliency measures, like this one, should be considered in future research to understand important economic implications for research studies on dairy science. Jointly analyzing production and financial data is important for understanding cow-level and herd-level factors influencing profitability.

This research emphasizes the importance of feed costs and their impacts on ECM in analyzing the effects on financial resiliency. Corn silage has proven to be the most effective feed in improving ECM levels and increasing the likelihood of resiliency, as it is commonly homegrown and high in energy, being economically and nutritionally efficient to dairy farms. Other homegrown and cheap feeds, like hay, show positive impacts on resiliency. This research suggests that maximizing ECM does not necessarily lead to resiliency, as feed expenses are a key influence on overall profitability. Balancing both milk revenue and feed costs is essential to financial resiliency.

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Appendix A – Feed Data Outliers

A.1 EW Feed Outliers

Table 16: Outliers Identified from the EW Feed Dataset, Including Total Observations Prior to Outliers Being Identified, Outlier Upper and Lower Limits, Number of Changes Made, Mean Values that Zeros were Changed to, and Number of Values Changed from Zero to the Mean.[1]

Variable	Total Obs >0	Equal Weighting							
		Upper Limit	Cut off	Changes	Lower Limit	Cut off	Changes	Zeros to avg.	Changes
Q_Whey_perday	4,814								
V_Whey_perday	4,814								
Q_Cottonseed_perday	12,591				0.3255	99%	497		
V_Cottonseed_perday	12,591				0.05442	99%	497		
Q_CornGluten_perday	4,126								
V_CornGluten_perday	4,126								
Q_BeetPulp_perday	11,332				0.08333	99%	170		
V_BeetPulp_perday	11,332				0.008333	99%	170		
Q_ProteinVit_perday	78,798	58.75	99.75%	138	1.526	99%	756		
V_ProteinVit_perday	78,798	9.068	99%	975	0.4778	99%	820		
Q_MilkReplace_perday	2,182								
V_MilkReplace_perday	2,182								
Q_Milk_perday	3,822								
V_Milk_perday	3,822								
Q_CreepStart_perday	272								
V_CreepStart_perday	272								
Q_CompRation_perday	22,342				0.01402	99%	559		
V_CompRation_perday	22,342	10.14	99%	581	0.02293	99%	559		
Q_Barley_perday	1,859								
V_Barley_perday	1,859								
Q_Corn_perday	89,627								
V_Corn_perday	89,627				0.1683	99%	801	0.94	30

Q CornSilage perday	91,808								
V CornSilage perday	91,808								
Q EarCorn perday	5,560	77.79	3 stdev	42					
V EarCorn perday	5,560				0.01267	99%	249		
Q AlfalfaHay perday	73,384				0.1852	99%	1,739		
V AlfalfaHay perday	73,384	4.345	99%	676	0.0106	99%	1,518	0.8357	771
Q GrassHay perday	47,183				0.1476	99%	572		
V GrassHay perday	47,183				0.006828	99%	417		
Q MixedHay perday	937								
V MixedHay perday	937								
Q ProteinSupp perday	785								
V ProteinSupp perday	785								
Q SmGrainHay perday	99								
V SmGrainHay perday	99								
Q AlfHaylage perday	55,820				2.32	99%	618		
V AlfHaylage perday	55,820				0.1693	99%	648		
Q GrasHaylage perday	545								
V GrasHaylage perday	545								
Q MixdHaylage perday	2,842								
V MixdHaylage perday	2,842								
Q Oatlage perday	8,680				0.2169	99%	166		
V Oatlage perday	8,680				0.00586	99%	166		
Q Oats perday	5,514				0.06456	99%	269		
V Oats perday	5,514				0.00404	99%	269		
Q Pasture perday	4,733				0.0008635	99%	83		
V Pasture perday	4,733				0.01295	99%	83		
Q RyeSilage perday	470								
V RyeSilage perday	470								
Q SorgSilage perday	1,963								
V SorgSilage perday	1,963								
Q Soybeans perday	1,188				0.003671	99%	23		
V Soybeans perday	1,188				0.0881	99%	23		
Q Stover perday	4,783								

V Stover perday	4,783								
Q Straw perday	35,413				0.1049	99%	138		
V Straw perday	35,413				0.006821	99%	583		
Q Triticale perday	70								
V Triticale perday	70								
Q SWheat perday	96								
V SWheat perday	96								
Q BarlSilage perday	3,609								
V BarlSilage perday	3,609								
Q OrgBarley perday	262								
V OrgBarley perday	262								
Q OrganicCorn perday	1,233								
V OrganicCorn perday	1,233				0.2131	99%	42	1.400	145
Q OrgCSilage perday	1,233								
V OrgCSilage perday	1,233								
Q OrgAlfHay perday	995								
V OrgAlfHay perday	995								
Q OrganicOats perday	165								
V OrganicOats perday	165								
Q OrgPasture perday	766								
V OrgPasture perday	766								
Q OrgGrHay perday	107								
V OrgGrHay perday	107								
Q OrganicFlax perday	111								
V OrganicFlax perday	111								
Q OrgMixdHay perday	410								
V OrgMixdHay perday	410								
Q DDGSdry perday	8,340								
V DDGSdry perday	8,340								
Q SwtCornSil perday	4,748								
V SwtCornSil perday	4,748								
Q DDGSwet perday	4,336								
V DDGSwet perday	4,336								

Q Baleage perday	1,222								
V Baleage perday	1,222								
Q Snaplage perday	2,590								
V Snaplage perday	2,590								
Q Hay perday	3,837								
V Hay perday	3,837							0.3862	30
Q TotalFeed perday	93,357	135.3	95%	4,589					
V TotalFeed perday	93,357	14.14	2 stdev	7,073					

[1] Outliers were identified for daily feed quantities and expenses, including lower and upper limits, expense values that were changed from zeros to mean market values, and how outliers were cut off to be set to missing. All variables that had zero observations were removed from the table.

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A.2 PGW Feed Outliers

Table 17: Outliers Identified from the PGW Feed Dataset, Including Total Observations Prior to Outliers Being Identified, Outlier Upper and Lower Limits, Number of Changes Made, Mean Values that Zeros were Changed to, and Number of Values Changed from Zero to the Mean.[1]

| Variable | Total Obs >0 | Production Group Weighting | | | | | | | |
		Upper Limit	Cut off	Changes	Lower Limit	Cut off	Changes	Zeros to avg.	Changes
Q_Whey_perday	4,235				2.137	99%	43		
V_Whey_perday	4,235				0.05739	99%	110		
Q_Cottonseed_perday	11,127				0.3219	99%	111		
V_Cottonseed_perday	11,127				0.05377	99%	112		
Q_CornGluten_perday	3,669				1.651	99%	37		
V_CornGluten_perday	3,669				0.1196	99%	37		
Q_BeetPulp_perday	10,003				0.08834	99%	100		
V_BeetPulp_perday	10,003				0.008554	99%	101		
Q_ProteinVit_perday	69,918	70.07	99.75%	175	1.541	99%	699		
V_ProteinVit_perday	69,918	7.649	2 stdev	3,725	0.4166	99%	760		
Q_MilkReplace_perday	1,938				0.00000619	99%	20		
V_MilkReplace_perday	1,938				0.005443	99%	37		
Q_Milk_perday	3,485				0.01527	99%	34		
V_Milk_perday	3,485				0.001527	99%	35		
Q_CreepStart_perday	256								
V_CreepStart_perday	256								
Q_CompRation_perday	19,947				0.01517	99%	199		
V_CompRation_perday	19,947	8.544	2 stdev	1,258	0.02449	99%	202		
Q_Barley_perday	1,673				0.1216	99%	16		
V_Barley_perday	1,673				0.008965	99%	17		
Q_Corn_perday	79,802				2.318	99%	798		
V_Corn_perday	79,802	3.664	99%	798	0.1317	99%	799	1.013	30
Q_CornSilage_perday	81,792				6.171	99%	818		
V_CornSilage_perday	81,792	4.118	99%	817	0.2833	99%	817		
Q_EarCorn_perday	4,831	84.29	3 stdev	37	0.6500	99%	49		

V EarCorn perday	4,831				0.01192	99%	48		
Q AlfalfaHay perday	65,294				0.1404	99%	653		
V AlfalfaHay perday	65,294	4.898	99%	655	0.009578	99%	655	0.8866	677
Q GrassHay perday	41,593				0.1413	99%	416		
V GrassHay perday	41,593				0.005694	99%	416		
Q MixedHay perday	860								
V MixedHay perday	860								
Q ProteinSupp perday	785								
V ProteinSupp perday	785								
Q SmGrainHay perday	90								
V SmGrainHay perday	90								
Q AlfHaylage perday	49,725				2.075	99%	498		
V AlfHaylage perday	49,725	4.345	99%	497	0.1417	99%	497		
Q GrasHaylage perday	521								
V GrasHaylage perday	521								
Q MixdHaylage perday	2,459				0.06428	99%	24		
V MixdHaylage perday	2,459				0.000964	99%	24		
Q Oatlage perday	7,932				0.2144	99%	80		
V Oatlage perday	7,932				0.005112	99%	79		
Q Oats perday	5,018				0.05342	99%	51		
V Oats perday	5,018				0.003561	99%	48		
Q Pasture perday	4,257				0.000682	99%	43		
V Pasture perday	4,257				0.01023	99%	43		
Q RyeSilage perday	465				0.4454	99%	5		
V RyeSilage perday	465				0.01782	99%	5		
Q SorgSilage perday	1,702				0.1188	99%	18		
V SorgSilage perday	1,702				0.006106	99%	18		
Q Soybeans perday	1,081				0.003624	99%	10		
V Soybeans perday	1,081				0.07849	99%	11		
Q Stover perday	4,254				0.3072	99%	43		
V Stover perday	4,254				0.02082	99%	43		
Q Straw perday	31,455				0.1092	99%	315		
V Straw perday	31,455				0.004787	99%	315		

Q Triticale perday	61								
V Triticale perday	61								
Q SWheat perday	85								
V SWheat perday	85								
Q BarlSilage perday	3,288				0.1705	99%	32		
V BarlSilage perday	3,288				0.006628	99%	32		
Q OrgBarley perday	253								
V OrgBarley perday	253								
Q OrganicCorn perday	1,088				0.9852	99%	12		
V OrganicCorn perday	1,088				0.1486	99%	10	1.513	134
Q OrgCSilage perday	1,088								
V OrgCSilage perday	1,088								
Q OrgAlfHay perday	881								
V OrgAlfHay perday	881								
Q OrganicOats perday	148								
V OrganicOats perday	148								
Q OrgPasture perday	681								
V OrgPasture perday	681								
Q OrgGrHay perday	98								
V OrgGrHay perday	98								
Q OrganicFlax perday	82								
V OrganicFlax perday	82								
Q OrgMixdHay perday	362								
V OrgMixdHay perday	362								
Q DDGSdry perday	7,518				0.3557	99%	75		
V DDGSdry perday	7,518				0.0389	99%	76		
Q SwtCornSil perday	4,211				0.02184	99%	43		
V SwtCornSil perday	4,211				0.001706	99%	42		
Q DDGSwet perday	3,864				0.8088	99%	38		
V DDGSwet perday	3,864				0.04289	99%	39		
Q Baleage perday	1,041				0.4868	99%	10		
V Baleage perday	1,041				0.02873	99%	10		
Q Snaplage perday	2,302				0.393	99%	24		

V Snaplage perday	2,302				0.01306	99%	24		
Q Hay perday	3,475				0.4089	99%	37		
V Hay perday	3,475				0.008397	99%	34	0.4596	30
Q TotalFeed perday	83,172	157.4	95%	4,158	24.11	99%	831		
V TotalFeed perday	83,172	16.00	2 stdev	5,112	2.276	99%	832		

[1] Outliers were identified for daily feed quantities and expenses, including lower and upper limits, expense values that were changed from zeros to average market values, and how outliers were cut off to be set to missing. All variables that had zero observations were removed from the table.

A.3 VW Feed Outliers

Table 18: Outliers Identified from the VW Feed Dataset, Including Total Observations Prior to Outliers Being Identified, Outlier Upper and Lower Limits, Number of Changes Made, Mean Values that Zeros were Changed to, and Number of Values Changed from Zero to the Mean.[1]

Variable	Total Obs >0	Volume Weighting							
		Upper Limit	Cut off	Changes	Lower Limit	Cut off	Changes	Zeros to avg.	Changes
Q_Whey_perday	4,235				2.137	99%	43		
V_Whey_perday	4,235				0.05739	99%	110		
Q_Cottonseed_perday	11,119				0.3219	99%	111		
V_Cottonseed_perday	11,119				0.05377	99%	112		
Q_CornGluten_perday	3,669				1.651	99%	37		
V_CornGluten_perday	3,669				0.1196	99%	37		
Q_BeetPulp_perday	9,993				0.08801	99%	100		
V_BeetPulp_perday	9,993				0.008509	99%	99		
Q_ProteinVit_perday	70,187	70.07	99.75%	176	1.549	99%	701		
V_ProteinVit_perday	70,187	7.66	2 stdev	3,762	0.4239	99%	761		
Q_MilkReplace_perday	1,938				0.00000619	99%	20		
V_MilkReplace_perday	1,938				0.005443	99%	37		
Q_Milk_perday	3,488				0.01586	99%	34		
V_Milk_perday	3,488				0.001581	99%	35		
Q_CreepStart_perday	256								
V_CreepStart_perday	256								
Q_CompRation_perday	20,102				0.01499	99%	201		
V_CompRation_perday	20,102	8.525	2 stdev	1,264	0.02405	99%	203		
Q_Barley_perday	1,675				0.1216	99%	16		
V_Barley_perday	1,675				0.008965	99%	17		
Q_Corn_perday	80,103				2.304	99%	802		
V_Corn_perday	80,103	3.662	99%	802	0.1301	99%	801	1.013	30
Q_CornSilage_perday	82,091				6.178	99%	821		
V_CornSilage_perday	82,091	4.117	99%	820	0.2832	99%	820		
Q_EarCorn_perday	4,832	85.32	3 stdev	38	0.65	99%	49		

V EarCorn perday	4,832				0.01192	99%	48		
Q AlfalfaHay perday	65,588				0.141	99%	656		
V AlfalfaHay perday	65,588	4.647	99%	817	0.009611	99%	657	0.894	677
Q GrassHay perday	41,585				0.1409	99%	416		
V GrassHay perday	41,585				0.005688	99%	416		
Q MixedHay perday	859								
V MixedHay perday	859								
Q ProteinSupp perday	785								
V ProteinSupp perday	785								
Q SmGrainHay perday	90								
V SmGrainHay perday	90								
Q AlfHaylage perday	49,711				2.067	99%	497		
V AlfHaylage perday	49,711	4.345	99%	498	0.1404	99%	498		
Q GrasHaylage perday	521								
V GrasHaylage perday	521								
Q MixdHaylage perday	2,459				0.06428	99%	24		
V MixdHaylage perday	2,459				0.000964	99%	24		
Q Oatlage perday	7,927				0.2144	99%	80		
V Oatlage perday	7,927				0.00515	99%	80		
Q Oats perday	5,017				0.05355	99%	51		
V Oats perday	5,017				0.003599	99%	51		
Q Pasture perday	4,256				0.000682	99%	43		
V Pasture perday	4,256				0.01023	99%	43		
Q RyeSilage perday	465				0.4454	99%	5		
V RyeSilage perday	465				0.01782	99%	5		
Q SorgSilage perday	1,701				0.1188	99%	18		
V SorgSilage perday	1,701				0.006106	99%	18		
Q Soybeans perday	1,079				0.003624	99%	10		
V Soybeans perday	1,079				0.08061	99%	11		
Q Stover perday	4,254				0.3113	99%	43		
V Stover perday	4,254				0.02106	99%	43		
Q Straw perday	31,464				0.1092	99%	315		
V Straw perday	31,464				0.004712	99%	315		

Q Triticale perday	61								
V Triticale perday	61								
Q SWheat perday	85								
V SWheat perday	85								
Q BarlSilage perday	3,288				0.1705	99%	32		
V BarlSilage perday	3,288				0.006628	99%	32		
Q OrgBarley perday	253								
V OrgBarley perday	253								
Q OrganicCorn perday	1,061				0.9852	99%	11		
V OrganicCorn perday	1,061				0.1615	99%	11	1.482	134
Q OrgCSilage perday	1,061								
V OrgCSilage perday	1,061								
Q OrgAlfHay perday	883								
V OrgAlfHay perday	883								
Q OrganicOats perday	149								
V OrganicOats perday	149								
Q OrgPasture perday	683								
V OrgPasture perday	683								
Q OrgGrHay perday	99								
V OrgGrHay perday	99								
Q OrganicFlax perday	53								
V OrganicFlax perday	53								
Q OrgMixdHay perday	363								
V OrgMixdHay perday	363								
Q DDGSdry perday	7,524				0.3565	99%	76		
V DDGSdry perday	7,524				0.03913	99%	76		
Q SwtCornSil perday	4,210				0.02096	99%	43		
V SwtCornSil perday	4,210				0.001638	99%	43		
Q DDGSwet perday	3,868				0.8088	99%	38		
V DDGSwet perday	3,868				0.04618	99%	38		
Q Baleage perday	1,042				0.4562	99%	11		
V Baleage perday	1,042				0.025	99%	10		
Q Snaplage perday	2,271				0.3681	99%	23		

V Snaplage perday	2,271				0.01298	99%	23		
Q Hay perday	3,477				0.4089	99%	37		
V Hay perday	3,477				0.008397	99%	34	0.4592	30
Q TotalFeed perday	83,444	157.2	95%	4,173	24.08	99%	834		
V TotalFeed perday	83,444	16.01	2 stdev	5,133	2.274	99%	835		

[1] Outliers were identified for daily feed quantities and expenses, including lower and upper limits, expense values that were changed from zeros to average market values, and how outliers were cut off to be set to missing. All variables that had zero observations were removed from the table.

Appendix B – Variables Explained

B.1   Feed Variables

After allocating the feed consumption, certain variables were not included in the analysis due to limited observations, as described in Tables 19-21. Feeds that had no observations in the dataset included cake, clover hay, green chop, clover/grass mixed hay, native grass hay, summer annual grass hay, intensive pasture, speltz, winter wheat, organic soybeans, organic sorghum silage, organic summer wheat, organic oatlage, and any user adds. Feeds that had minimal observations or did not pertain to the cow herd included whey, milk replacer, milk, creep start, triticale, and summer wheat. Straw and stover were chosen to be left out of analysis as they were likely used for bedding instead of only feeding. Organic feeds had few observations from only three farms and were excluded from further analysis.

B.2   Forages

Forages are defined as high fiber feeds that can be fed in a fresh, dried, or ensiled state. Forages include silages, hays, and pasture. Table 19 includes the number of observations for the quantities and expenses of each forage in our dataset from 2012-2018.

Table 19: Total Observations for Quantities and Expenses of Forages and Reason Not Used.

Variable	Description	EW Obs	PGW Obs	VW Obs	Considered?	Reason not Used
Q_CornSilage	Quantity of Corn Silage	91,516	91,516	80,974	yes	
V_CornSilage	Expense (Dollar Value) of Corn Silage	91,516	91,516	80,158	yes	
Q_AlfalfaHay	Quantity of Alfalfa Hay	71,368	72,537	64,641	yes	
V_AlfalfaHay	Expense (Dollar Value) of Alfalfa Hay	70,916	71,336	63,984	yes	
Q_CloverHay	Quantity of Clover Hay	0	0	0	no	No observations
V_CloverHay	Expense (Dollar Value) of Clover Hay	0	0	0	no	No observations
Q_GrassHay	Quantity of Grass Hay	46,453	46,603	41,177	yes	
V_GrassHay	Expense (Dollar Value) of Grass Hay	46,607	46,513	41,177	yes	
Q_GreenChop	Quantity of Green Chop	0	0	0	no	No observations
V_GreenChop	Expense (Dollar Value) of Green Chop	0	0	0	no	No observations
Q_MixedHay	Quantity of Mixed Alfalfa/Grass Hay	935	935	860	yes	
V_MixedHay	Expense (Dollar Value) of Mixed Alfalfa/Grass Hay	935	935	860	yes	
Q_AlfGrMixed	Quantity of Mixed Clover/Grass Hay	0	0	0	no	No observations
V_AlfGrMixed	Expense (Dollar Value) of Mixed Clover/Grass Hay	0	0	0	no	No observations
Q_NativeGrass	Quantity of Native Grass Hay	0	0	0	no	No observations
V_NativeGrass	Expense (Dollar Value) of Native Grass Hay	0	0	0	no	No observations
Q_SmGrainHay	Quantity of Small Grain Hay	99	99	90	yes	
V_SmGrainHay	Expense (Dollar Value) of Small Grain Hay	99	99	90	yes	
Q_SmrAnGrass	Quantity of Summer Annual Grass Hay	0	0	0	no	No observations
V_SmrAnGrass	Expense (Dollar Value) of Summer Annual Grass Hay	0	0	0	no	No observations
Q_AlfHaylage	Quantity of Alfalfa Haylage	55,104	55,143	49,227	yes	
V_AlfHaylage	Expense (Dollar Value) of Alfalfa Haylage	55,074	55,185	48,731	yes	

Q_GrasHaylage	Quantity of Grass Haylage	543	543	521	yes	
V_GrasHaylage	Expense (Dollar Value) of Grass Haylage	543	543	521	yes	
Q_MixdHaylage	Quantity of Mixed Haylage	2,842	2,729	2,435	yes	
V_MixdHaylage	Expense (Dollar Value) of Mixed Haylage	2,842	2,729	2,435	yes	
Q_Oatlage	Quantity of Oatlage	8,487	8,570	7,852	yes	
V_Oatlage	Expense (Dollar Value) of Oatlage	8,487	8,570	7,853	yes	
Q_Pasture	Quantity of Pasture	4,631	4,668	4,214	yes	
V_Pasture	Expense (Dollar Value) of Pasture	4,631	4,621	4,214	yes	
Q_IntPasture	Quantity of Intensive Pasture	0	0	0	no	No observations
V_IntPasture	Expense (Dollar Value) of Intensive Pasture	0	0	0	no	No observations
Q_RyeSilage	Quantity of Rye Silage	465	465	460	yes	
V_RyeSilage	Expense (Dollar Value) of Rye Silage	465	465	460	yes	
Q_SorgSilage	Quantity of Sorghum Silage	1,946	1,859	1,684	yes	
V_SorgSilage	Expense (Dollar Value) of Sorghum Silage	1,946	1,859	1,684	yes	
Q_Stover	Quantity of Stover	4,776	4,776	4,211	no	Bedding
V_Stover	Expense (Dollar Value) of Stover	4,776	4,744	4,211	no	Bedding
Q_Straw	Quantity of Straw	35,239	34,965	31,140	no	Bedding
V_Straw	Expense (Dollar Value) of Straw	34,794	35,115	31,140	no	Bedding
Q_BarlSilage	Quantity of Barley Silage	3,602	3,467	3,256	yes	
V_BarlSilage	Expense (Dollar Value) of Barley Silage	3,602	3,467	3,256	yes	
Q_OrgCSilage	Quantity of Organic Corn Silage	1228	1228	1088	no	Organic, too few observations
V_OrgCSilage	Expense (Dollar Value) of Organic Corn Silage	1228	1228	1088	no	Organic, too few observations
Q_OrgAlfHay	Quantity of Organic Alfalfa Hay	992	992	881	no	Organic, too few observations
V_OrgAlfHay	Expense (Dollar Value) of Organic Alfalfa Hay	992	992	881	no	Organic, too few observations
Q_OrgPasture	Quantity of Organic Pasture	764	764	681	no	Organic, too few observations
V_OrgPasture	Expense (Dollar Value) of Organic Pasture	764	764	681	no	Organic, too few observations
Q_OrgSorgSlg	Quantity of Organic Sorghum Silage	0	0	0	no	No observations
V_OrgSorgSlg	Expense (Dollar Value) of Organic Sorghum Silage	0	0	0	no	No observations
Q_OrgGrHay	Quantity of Organic Grass Hay	106	106	98	no	Organic, too few observations
V_OrgGrHay	Expense (Dollar Value) of Organic Grass Hay	106	106	98	no	Organic, too few observations

Q_OrgOatlage	Quantity of Organic Oatlage	0	0	0	no	No observations
V_OrgOatlage	Expense (Dollar Value) of Organic Oatlage	0	0	0	no	No observations
Q_OrgMixdHay	Quantity of Organic Mixed Hay	410	410	362	no	Organic, too few observations
V_OrgMixdHay	Expense (Dollar Value) of Organic Mixed Hay	410	410	362	no	Organic, too few observations
Q_SwtCornSil	Quantity of Sweet Corn Silage	4,738	4,486	4,168	yes	
V_SwtCornSil	Expense (Dollar Value) of Sweet Corn Silage	4,738	4,486	4,169	yes	
Q_Baleage	Quantity of Baleage Hay	1,221	1,221	1,031	yes	
V_Baleage	Expense (Dollar Value) of Baleage Hay	1,221	1,221	1,031	yes	
Q_Snaplage	Quantity of Corn Snaplage	2,584	2,584	2,278	yes	
V_Snaplage	Expense (Dollar Value) of Hay Snaplage	2,584	2,584	2,278	yes	
Q_Hay	Quantity of Hay	3,833	3,833	3,438	yes	
V_Hay	Expense (Dollar Value) of Hay	3,833	3,582	3,441	yes	

B.3   Protein Sources

Protein sources are defined as concentrate feeds that are high in protein or fed to dairy cattle as a protein source. Table 20 includes the number of observations for the quantities and expenses of each protein source in our dataset from 2012-2018.

Table 20: Total Observations for Quantities and Expenses of Protein Sources and Reason Not Used.

Variable	Description	EW Obs	PGW Obs	VW Obs	Considered?	Reason not Used
Q_Whey	Quantity of Whey	4,812	4,812	4,192	no	Calf feed
V_Whey	Expense (Dollar Value) of Whey	4,812	4,812	4,192	no	Calf feed
Q_DDG	Quantity of Corn Distillers Grain (dry)	0	0	0	no	No observations
V_DDG	Volume of Corn Distillers Grain (dry)	0	0	0	no	No observations
Q_ProteinVit	Quantity of Protein, Vitamins, and Minerals	77,658	77,532	69,044	yes	
V_ProteinVit	Expense (Dollar Value) of Protein, Vitamins, and Minerals	76,825	77,192	65,660	yes	
Q_MilkReplacer	Quantity of Milk Replacer	2,167	2,167	1,918	no	Calf feed
V_MilkReplacer	Expense (Dollar Value) of Milk Replacer	2,167	2,167	1,919	no	Calf feed
Q_Milk	Quantity of Milk	3,819	3,819	3,451	no	Calf feed
V_Milk	Expense (Dollar Value) of Milk	3,819	3,819	3,450	no	Calf feed
Q_CreepStart	Quantity of Creep / Starter	272	272	256	no	Calf feed
V_CreepStart	Expense (Dollar Value) of Creep / Starter	272	272	256	no	Calf feed
Q_CompRation	Quantity of Complete Ration	21,659	21,888	19,748	yes	
V_CompRation	Expense (Dollar Value) of Complete Ration	21,515	21,705	18,928	yes	
Q_ProteinSupp	Quantity of Protein Supplement	785	785	785	yes	
V_ProteinSupp	Expense (Dollar Value) of Protein Supplement	785	785	785	yes	
Q_Soybeans	Quantity of Soybeans	1,164	1,174	1,071	yes	
V_Soybeans	Expense (Dollar Value) of Soybeans	1,164	1,174	1,070	yes	
Q_SoyOrganic	Quantity of Organic Soybeans	0	0	0	no	No observations
V_SoyOrganic	Expense (Dollar Value) of Organic Soybeans	0	0	0	no	No observations
Q_DDGSdry	Quantity of dry DDGS	8,304	8,304	7,443	yes	
V_DDGSdry	Expense (Dollar Value) of dry DDGS	8,304	8,304	7,442	yes	

| Q_DDGSwet | Quantity of wet DDGS | 4,320 | 4,320 | 3,826 | yes | |
| V_DDGSwet | Expense (Dollar Value) of wet DDGS | 4,320 | 4,320 | 3,825 | yes | |

B.4   Other Concentrates

Other concentrates are defined as the high energy feeds or concentrates that are not used as a protein source in dairy cattle rations. Table 21 includes the number of observations for the quantities and monetary values of each concentrate other than protein sources in our dataset from 2012-2018.

Table 21: Total Observations for Quantities and Expenses of Other Concentrates and Reason Not Used.

Variable	Description	EW Obs	PGW Obs	VW Obs	Considered?	Reason not Used
Q_Cake	Quantity of Cake	0	0	0	no	No observations
V_Cake	Expense (Dollar Value) of Cake	0	0	0	no	No observations
Q_Cottonseed	Quantity of Cottonseed	12,002	12,211	11,016	yes	
V_Cottonseed	Expense (Dollar Value) of Cottonseed	12,002	12,211	11,015	yes	
Q_CornGluten	Quantity of Corn Gluten	4,123	4,123	3,632	yes	
V_CornGluten	Expense (Dollar Value) of Corn Gluten	4,123	4,123	3,632	yes	
Q_BeetPulp	Quantity of Beet Pulp (dry)	11,049	11,143	9,903	yes	
V_BeetPulp	Expense (Dollar Value) of Beet Pulp (dry)	11,049	11,049	9,902	yes	
Q_Barley	Quantity of Barley	1,851	1,792	1,657	yes	
V_Barley	Expense (Dollar Value) of Barley	1,851	1,805	1,656	yes	
Q_Corn	Quantity of Corn	89,334	88,386	79,004	yes	
V_Corn	Expense (Dollar Value) of Corn	88,533	87,845	78,205	yes	
Q_EarCorn	Quantity of Ear Corn	5,514	5,514	4,745	yes	
V_EarCorn	Expense (Dollar Value) of Ear Corn	5,307	5,415	4,783	yes	
Q_CottonSeed	Quantity of Cotton Seed	0	0	0	no	No observations
V_CottonSeed	Expense (Dollar Value) of Cotton Seed	0	0	0	no	No observations
Q_Oats	Quantity of Oats	5,211	5,313	4,967	yes	
V_Oats	Expense (Dollar Value) of Oats	5,211	5,313	4,970	yes	
Q_Speltz	Quantity of Speltz	0	0	0	no	No observations
V_Speltz	Expense (Dollar Value) of Speltz	0	0	0	no	No observations

Q_Triticale	Quantity of Triticale	70	70	61	no	Too few observations
V_Triticale	Expense (Dollar Value) of Triticale	70	70	61	no	Too few observations
Q_SWheat	Quantity of Spring Wheat	96	96	85	no	Too few observations
V_SWheat	Expense (Dollar Value) of Spring Wheat	96	96	85	no	Too few observations
Q_WWheat	Quantity of Winter Wheat	0	0	0	no	No observations
V_WWheat	Expense (Dollar Value) of Winter Wheat	0	0	0	no	No observations
Q_OrgBarley	Quantity of Organic Barley	260	260	253	no	Organic, too few observations
V_OrgBarley	Expense (Dollar Value) of Organic Barley	260	260	253	no	Organic, too few observations
Q_OrganicCorn	Quantity of Organic Corn	1228	1228	1076	no	Organic, too few observations
V_OrganicCorn	Expense (Dollar Value) of Organic Corn	1186	1204	1078	no	Organic, too few observations
Q_OrganicOats	Quantity of Organic Oats	165	165	148	no	Organic, too few observations
V_OrganicOats	Expense (Dollar Value) of Organic Oats	165	165	148	no	Organic, too few observations
Q_OrgSWheat	Quantity of Organic Spring Wheat	0	0	0	no	No observations
V_OrgSWheat	Expense (Dollar Value) of Organic Spring Wheat	0	0	0	no	No observations
Q_OrganicFlax	Quantity of Organic Flax	111	111	82	no	Organic, too few observations
V_OrganicFlax	Expense (Dollar Value) of Organic Flax	111	111	82	no	Organic, too few observations
Q_UserAdd	Quantity of User Added	0	0	0	no	No observations
V_UserAdd	Expense (Dollar Value) of User Added	0	0	0	no	No observations

Appendix C – Summary Statistics for Variables Considered in the ECM Regressions

Table 22: Summary Statistics for Continuous Variables Considered for Use in the ECM Regressions for the EW and PGW Datasets.[1]

Continuous Variable	EQUAL WEIGHTING					PRODUCTION GROUP WEIGHTING				
	N	Mean	Std. Dev.	Min	Max	N	Mean	Std. Dev.	Min	Max
ECM	85,743	17540.64	9334.28	22.24	48205.04	85,743	17540.64	9334.28	22.24	48205.04
Q_Cottonseed	12,002	859.55	513.79	1.78	2936.73	12,211	847.09	580.07	1.50	3195.50
Q_CornGluten	4,123	1389.43	878.33	2.73	4339.05	4,123	1389.43	983.32	2.27	4729.65
Q_BeetPulp	11,049	1710.78	2115.85	0.70	11902.07	11,143	1696.62	2214.59	0.58	13045.56
Q_ProteinVit	77,658	3541.28	2443.48	1.53	21033.64	77,532	3542.64	2658.99	1.86	21880.72
Q_CompRation	21,659	3535.75	4368.48	0.09	35219.13	21,888	3498.81	4560.14	0.07	40255.30
Q_Barley	1,851	370.09	812.80	0.32	7179.84	1,792	380.37	868.90	0.28	7847.50
Q_Corn	89,334	3026.20	2037.13	1.93	17530.06	88,386	3053.00	2231.99	2.86	19127.58
Q_CornSilage	91,516	4972.92	3150.30	6.52	24544.17	91,516	4972.92	3472.17	5.58	28865.81
Q_EarCorn	5,514	552.86	631.38	0.83	9303.70	5,514	552.86	674.61	0.69	10389.95
Q_AlfalfaHay	71,368	2536.73	2819.00	0.19	27601.38	72,537	2496.70	2973.52	0.16	30411.39
Q_GrassHay	46,453	425.77	567.22	0.28	11422.35	46,603	424.62	595.06	0.23	12992.05
Q_MixedHay	935	688.82	586.56	1.48	2491.15	935	688.82	634.35	1.25	2685.59
Q_ProteinSupp	785	545.22	328.58	3.37	1229.88	785	545.22	380.14	2.76	1340.59
Q_SmGrainHay	99	474.75	272.13	4.08	744.12	99	474.75	309.01	3.37	818.41
Q_AlfHaylage	55,104	3160.64	2283.35	4.48	17900.29	55,143	3159.67	2493.49	3.85	19411.18
Q_GrasHaylage	543	620.01	894.80	0.91	3824.51	543	620.01	939.49	0.74	4215.34
Q_MixdHaylage	2,842	404.56	555.68	0.36	9775.42	2,729	420.84	573.29	0.50	9500.64
Q_Oatlage	8,487	683.26	880.38	0.32	7058.03	8,570	677.47	929.77	0.27	7812.82
Q_Oats	5,211	342.42	520.93	0.12	5326.05	5,313	336.32	545.87	0.10	5811.42
Q_Pasture	4,631	1.75	2.69	0.00	17.29	4,668	1.74	2.78	0.00	20.75
Q_RyeSilage	465	528.64	691.26	0.91	3110.40	465	528.64	745.46	0.74	3360.90
Q_SorgSilage	1,946	412.14	614.76	0.28	4178.81	1,859	430.70	659.54	0.24	4548.18
Q_Soybeans	1,164	8.81	5.25	0.01	24.08	1,174	8.74	5.86	0.01	25.87

Q_BarlSilage	3,602	386.85	437.70	0.27	2694.68	3,467	400.75	464.80	0.22	2941.57
Q_OrgBarley	260	993.20	525.88	3.66	2943.51	260	993.20	584.41	3.17	3122.15
Q_OrganicCorn	1,228	1584.32	1238.06	4.44	6533.36	1228	1584.32	1337.53	3.87	6929.86
Q_OrgCSilage	1,228	2704.12	1500.23	8.51	10732.07	1228	2704.12	1680.56	7.42	11383.39
Q_OrgAlfHay	992	5058.56	2662.04	19.12	19163.46	992	5058.56	2963.12	16.68	20326.47
Q_OrganicOats	165	697.41	289.29	6.32	981.78	165	697.41	335.06	5.57	1111.99
Q_OrgPasture	764	2.20	1.89	0.01	9.21	764	2.20	1.99	0.01	10.62
Q_OrgGrHay	106	242.75	145.18	1.79	543.56	106	242.75	157.38	1.57	606.83
Q_OrganicFlax	111	95.00	33.08	0.35	127.17	111	95.00	39.71	0.31	152.54
Q_OrgMixdHay	410	760.98	316.20	2.68	1056.19	410	760.98	370.99	2.34	1193.67
Q_DDGSdry	8,304	864.89	1052.61	0.38	6534.56	8,304	864.89	1119.86	0.32	7112.02
Q_SwtCornSil	4,738	124.81	123.67	0.04	559.19	4,486	131.42	131.53	0.24	628.34
Q_DDGSwet	4,320	2239.30	2006.12	1.20	15681.07	4,320	2239.30	2137.66	0.97	17187.63
Q_Baleage	1,221	1078.40	1545.94	2.32	5078.26	1,221	1078.40	1609.58	1.94	5624.83
Q_Snaplage	2,584	1027.62	1191.32	0.75	3508.48	2,584	1027.62	1252.91	0.62	3941.74
Q_Hay	3,833	1565.07	2169.94	0.58	11984.40	3,833	1565.07	2266.10	0.47	13298.85
Q_TotalFeed	88,498	16550.87	9324.57	18.29	49503.25	88,301	15972.45	9964.79	15.15	47309.63
Q_allCornSilage	91,516	4979.38	3150.95	6.52	24544.17	91,516	4979.36	3473.39	5.58	28865.81
Q_allHay_noAlf	51,143	517.53	860.89	0.28	11984.40	51,293	516.22	895.82	0.23	13298.85
Q_allHaylage_noAlf	14,671	767.32	1059.00	0.32	9775.42	14,641	769.28	1110.43	0.27	9500.64
Q_allHay	83,796	2476.37	2845.08	0.40	32721.18	83,796	2477.23	3003.58	0.33	37217.84
Q_allHaylage	59,245	3129.74	2325.13	0.75	17900.29	59,284	3128.95	2530.88	0.62	19411.18
Q_allCorn	89,376	3058.88	2044.20	1.93	17530.06	88,428	3086.02	2242.10	2.86	19127.58
Q_PVM_I	90,176	3903.67	2952.62	0.73	35219.13	90,050	3905.37	3182.24	0.61	40255.30
Q_PVM_II	90,237	4419.33	3431.62	0.73	35219.13	90,121	4421.56	3696.23	0.61	40255.30
Q_PVM_III	90,395	4494.81	3439.64	0.53	35220.93	90,279	4497.16	3710.78	0.43	40257.34
percrough	88,498	44.08	10.96	0.00	80.86	88,301	44.24	10.95	0.00	85.30
SCS	95,354	2.84	1.84	0.01	9.70	95,354	2.84	1.84	0.01	9.70
Lactation_No	99,685	2.17	1.38	1.00	13.00	99,685	2.17	1.38	1.00	13.00

[1] All observations for feed variables equivalent to zero or too small to be considered for analysis were not included in summary statistics.

Table 23: Summary Statistics for Continuous Variables Considered for Use in the ECM Regressions for the VW Dataset.[1]

Continuous Variable	VOLUME WEIGHTING				
	N	Mean	Std. Dev.	Min	Max
ECM	85,743	17540.64	9334.28	22.24	48205.04
Q_Cottonseed	11,016	939.68	577.95	0.37	3801.79
Q_CornGluten	3,632	1575.62	937.42	3.12	4714.59
Q_BeetPulp	9,903	1908.96	2393.80	0.74	15990.29
Q_ProteinVit	69,044	3977.37	2688.18	1.71	21131.69
Q_CompRation	19,748	3877.97	4772.44	0.02	48025.14
Q_Barley	1,657	413.19	893.36	0.31	10042.32
Q_Corn	79,004	3417.39	2231.24	2.79	20925.36
Q_CornSilage	80,974	5612.47	3409.89	6.93	32494.12
Q_EarCorn	4,745	641.81	661.82	1.51	10403.65
Q_AlfalfaHay	64,641	2801.64	3127.72	0.14	35861.24
Q_GrassHay	41,177	480.54	627.62	0.26	15273.01
Q_MixedHay	860	748.89	658.14	1.46	3069.28
Q_ProteinSupp	785	545.22	325.20	2.74	1336.32
Q_SmGrainHay	90	522.22	321.86	4.53	1094.55
Q_AlfHaylage	49,227	3539.58	2472.15	4.66	21433.40
Q_GrasHaylage	521	646.19	953.09	0.88	4977.56
Q_MixdHaylage	2,435	472.03	603.84	0.61	9725.56
Q_Oatlage	7,852	739.41	929.78	0.38	8010.39
Q_Oats	4,967	359.94	547.07	0.10	5505.13
Q_Pasture	4,214	1.93	3.03	0.00	29.10
Q_RyeSilage	460	534.20	690.85	0.88	3759.15
Q_SorgSilage	1,684	476.05	699.70	0.21	5348.20
Q_Soybeans	1,071	9.58	5.88	0.01	26.69
Q_BarlSilage	3,256	427.71	480.88	0.31	3076.48
Q_OrgBarley	253	1020.68	536.94	4.11	2516.78

Q_OrganicCorn	1076	1805.57	1397.22	4.75	6157.21
Q_OrgCSilage	1088	3052.07	1672.61	9.10	9176.23
Q_OrgAlfHay	881	5695.91	2861.25	20.44	16385.30
Q_OrganicOats	148	777.51	305.77	7.28	1414.29
Q_OrgPasture	681	2.47	2.07	0.01	10.84
Q_OrgGrHay	98	262.57	147.82	2.06	670.49
Q_OrganicFlax	82	128.60	35.66	0.54	201.33
Q_OrgMixdHay	362	861.88	395.29	2.87	1833.45
Q_DDGSdry	7,443	964.23	1124.20	0.36	8315.87
Q_SwtCornSil	4,168	141.85	145.93	0.17	948.14
Q_DDGSwet	3,826	2527.81	2248.29	1.16	21067.33
Q_Baleage	1,031	1276.40	1823.66	2.97	7661.63
Q_Snaplage	2,278	1165.30	1377.15	0.86	5782.99
Q_Hay	3,438	1744.56	2233.31	0.52	17177.18
Q_TotalFeed	78,183	18733.58	10324.66	26.62	57436.15
Q_allCornSilage	81,053	5614.29	3413.77	1.05	32494.12
Q_allHay_noAlf	45,388	583.32	924.43	0.26	17177.18
Q_allHaylage_noAlf	13,189	853.92	1173.96	0.38	9725.56
Q_allHay	74,658	2780.37	3154.98	0.34	43752.02
Q_allHaylage	52,980	3501.43	2525.90	0.86	21433.40
Q_allCorn	79,045	3454.15	2235.65	2.79	20925.36
Q_PVM_I	80,354	4375.93	3239.45	1.66	48025.14
Q_PVM_II	80,452	4952.30	3789.67	0.01	48025.14
Q_PVM_III	80,614	5035.62	3796.37	0.01	48027.58
percrough	78,183	44.32	11.00	0.00	88.44
SCS	95,354	2.84	1.84	0.01	9.70
Lactation_No	99,685	2.17	1.38	1.00	13.00

[1] All observations for feed variables equivalent to zero or too small to be considered for analysis were not included in summary statistics.

Table 24: Summary Statistics for Binary Variables Considered for Use in the ECM Regressions.[1]

Variable	EQUAL WEIGHTING			PRODUCTION GROUP WEIGHTING			VOLUME WEIGHTING		
	= 1	= 0	Percent	= 1	= 0	Percent	= 1	= 0	Percent
Cottonseed	12,002	80,766	12.94%	12,211	80,564	13.16%	11,016	88,558	11.06%
CornGluten	4,123	89,231	4.42%	4,123	88,936	4.43%	3,632	96,016	3.64%
BeetPulp	11,049	82,025	11.87%	11,143	81,840	11.98%	9,903	89,682	9.94%
ProteinVit	77,658	14,559	84.21%	77,532	14,508	84.24%	69,044	29,767	69.87%
CompRation	21,659	71,015	23.37%	21,888	70,841	23.60%	19,748	79,738	19.85%
Barley	1,851	91,498	1.98%	1,792	91,208	1.93%	1,657	98,012	1.66%
Corn	89,334	3,730	95.99%	88,386	3,725	95.96%	79,004	19,883	79.89%
CornSilage	91,516	1,549	98.34%	91,516	1,543	98.34%	80,974	17,893	81.90%
EarCorn	5,514	87,797	5.91%	5,514	87,503	5.93%	4,745	94,854	4.76%
AlfalfaHay	71,368	19,973	78.13%	72,537	19,952	78.43%	64,641	34,391	65.27%
GrassHay	46,453	46,174	50.15%	46,603	46,035	50.31%	41,177	58,092	41.48%
MixedHay	935	92,420	1.00%	935	92,124	1.00%	860	98,825	0.86%
ProteinSupp	785	92,572	0.84%	785	92,274	0.84%	785	98,900	0.79%
SmGrainHay	99	93,258	0.11%	99	92,960	0.11%	90	99,595	0.09%
AlfHaylage	55,104	37,537	59.48%	55,143	37,341	59.62%	49,227	49,960	49.63%
GrasHaylage	543	92,812	0.58%	543	92,516	0.58%	521	99,164	0.52%
MixdHaylage	2,842	90,515	3.04%	2,729	90,217	2.94%	2,435	97,226	2.44%
Oatlage	8,487	84,677	9.11%	8,570	84,406	9.22%	7,852	91,753	7.88%
Oats	5,211	87,843	5.60%	5,313	87,579	5.72%	4,967	94,667	4.99%
Pasture	4,631	88,624	4.97%	4,668	88,345	5.02%	4,214	95,428	4.23%
RyeSilage	465	92,887	0.50%	465	92,594	0.50%	460	99,220	0.46%
SorgSilage	1,946	91,394	2.08%	1,859	91,113	2.00%	1,684	97,983	1.69%
Soybeans	1,164	92,169	1.25%	1,174	91,873	1.26%	1,071	98,604	1.07%
BarlSilage	3,602	89,748	3.86%	3,467	89,457	3.73%	3,256	96,397	3.27%

OrgBarley	260	93,095	0.28%	260	92,799	0.28%	253	99,432	0.25%
OrganicCorn	1228	92,124	1.32%	1228	91,831	1.32%	1076	98,597	1.08%
OrgCSilage	1228	92,124	1.32%	1228	91,831	1.32%	1088	98,597	1.09%
OrgAlfHay	992	92,362	1.06%	992	92,067	1.07%	881	98,804	0.88%
OrganicOats	165	93,192	0.18%	165	92,894	0.18%	148	99,537	0.15%
OrgPasture	764	92,591	0.82%	764	92,295	0.82%	681	99,004	0.68%
OrgGrHay	106	93,250	0.11%	106	92,953	0.11%	98	99,587	0.10%
OrgMixdHay	111	93,246	0.12%	111	92,948	0.12%	82	99,603	0.08%
DDGSdry	410	92,947	0.44%	410	92,649	0.44%	362	99,323	0.36%
SwtCornSil	8,304	85,017	8.90%	8,304	84,755	8.92%	7,443	92,167	7.47%
DDGSwet	4,738	88,609	5.08%	4,486	88,321	4.83%	4,168	95,474	4.18%
Baleage	4,320	89,021	4.63%	4,320	88,739	4.64%	3,826	95,821	3.84%
Snaplage	1,221	92,135	1.31%	1,221	91,838	1.31%	1,031	98,644	1.03%
Hay	2,584	90,767	2.77%	2,584	90,475	2.78%	2,278	97,383	2.29%
lact2	3,833	89,520	4.11%	3,833	89,226	4.12%	3,438	96,210	3.45%
lact3	25,735	74,312	25.72%	25,735	74,312	25.72%	25,735	74,312	25.72%
allDDGS	32,357	67,690	32.34%	32,357	67,690	32.34%	32,357	67,690	32.34%
percrough_range	15,627	77,730	16.74%	15,627	77,432	16.79%	13,963	85,722	14.01%

[1] All observations for feed variables equivalent to zero or too small to be considered for analysis were not included in summary statistics.

Appendix D – Abbreviations Defined

Table 25: Abbreviations Used in the Text and Their Definitions.[1]

Abbreviation	Definition
USDA-ERS	United States Department of Agriculture Economic Research Service
NRC	National Research Council
ECM	Energy Corrected Milk
DMI	Dry Matter Intake
CP	Crude Protein
NFC	Non-Fiber Carbohydrates
VFA	Volatile Fatty Acids
BHB	Beta-Hydroxybutyrate
RDP	Rumen Degradable Protein
RUP	Rumen Undegradable Protein
MP	Metabolizable Protein
NE	Net Energy
DM	Dry Matter
MFD	Milk Fat Depression
IOFC	Income Over Feed Cost
ME	Mature Equivalent
DHIA	Dairy Herd Improvement Association
DIM	Days in Milk
SCS	Somatic Cell Score
EW	Equal Weighting
PGW	Production Group Weighting
VW	Volume Weighting
NEL	Net Energy of Lactation
DDGS	Dried Distillers Grains
PVM	Protein, Vitamins, and Minerals
NFI	Net Farm Income
RROA	Rate of Return on Assets

[1] Abbreviations are listed in the order in which they appear in the text.