The Udder Vulnerability of Conventional Dairy Farming to Climate Change

A look into the future for Dairy Farming in Madison County

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**Executive Summary:** Dairy farming, an integral component of Madison's County's agricultural sector and cultural heritage, faces a rapidly changing environmental landscape. As climate change manifestations linger on the horizon, the social, economic, and environmental pillars of sustainability associated with Madison County's conventional dairy farming are under threat. Therefore, this paper seeks to analyze and identify both the key vulnerabilities of the dairy industry to climate change as well as its ability to adapt to these transformations. To do so, literature review, personal interviews, and new data analysis are combined to create a holistic understanding of the dairy industry specifically in Madison County. The findings suggest that conventional dairy farms are particularly prone to heat stress via temperature increases, as well as torrential rains and changes in precipitations patterns. These climate change symptoms will not only affect the productivity of individual cows, but also will negatively impact feed costs and crop consistency. While the dairy industry is ill equipped to handle change with financial means due to low profit margins and uncertain prices, it does benefit from a cohort of cooperatives and insurance programs, along with a supportive community. Ultimately, the paper proposes two policy measures that aim to buttress the financial distress suffered by dairy farms in an effort to increase their adaptive capacities and protect against climate change vulnerabilities.
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**Research Question**

According to the 2012 Census of Agriculture, milk from dairy cows accounts for over sixty-three percent of agriculture by revenue in Madison County. This conventional dairy farming industry, as any agricultural industry, is particularly vulnerable to climate change in that it relies upon balanced natural systems in order to survive. Dairy farming makes up the largest portion of agriculture in Madison County, and its viability as a livelihood may therefore be tied to how well dairy farmers can adapt their practices to a changing climate and mitigate related risks. As such, to research the sustainability of this sector we will examine the following questions:

What climate change related challenges do dairy farmers in Madison County face today, and how will these challenges impact the viability of dairy farm production over the next ten to twenty years? What aspects of dairy farming are most vulnerable to climate change? How can dairy farmers adapt their practices to maintain sustainable production (by minimizing vulnerability) in the context of Madison’s changing climate? And finally, will the degradation of dairy farming as a livelihood erode its cultural resonance in the area?

**Significance of the Project**

In Madison County, where agriculture drives much of local economic activity and cultural heritage, it is imperative that farmers improve their sustainability in the face of changing climate. Conventional dairy farming is the largest farming sector in Madison (USDA, 2012), meaning that dairy sustainability specifically, is of the utmost importance
over the coming decades. To be sustainable, farmers in Madison County must anticipate and adapt to future climate condition changes, and mitigate their vulnerability to the effects of these changes. Understanding the factors surrounding the sustainability of conventional dairy farming, as this paper aims to do, therefore represents a crucial step towards protecting the industry from the growing perils of a changing climate.

According to Tom Theis, “there are three dimensions that sustainability seeks to integrate: economic, environmental, and social” (Theis, 2013, p.6). The economic pillar relates to “the flow of financial capital, and the facilitation of commerce”, the environmental pillar to “the goods and services produced by the world’s ecosystems”, and the social pillar to the “interactions between institutions/firms and people” in the context of collective well being (Theis, 2013, p.6). As such, improving the sustainability of conventional dairy farming must incorporate protecting economic profitability, environmental viability, and cultural relevance throughout Madison. To do so would therefore ensure a bright future for this crucial livelihood in Madison County.

**Research Methods Description**

This paper’s research comes in three forms: farm visits and farmer interviews, literature review, and milk production data analysis. These three approaches aim to provide qualitative and quantitative insight into the exact ways in which changing climate impacts the sustainability of Madison’s conventional dairy industry.

First, visiting the five hundred-plus cow Morrisville State College Dairy Complex in Morrisville and interviewing Manager Shawn Bossard offered a qualitative overview of Madison’s conventional dairy industry. Asking Bossard the broad research questions
yielded key identification of the major challenges posed by climate change, as well as the major vulnerabilities of the industry. Second, visiting the eighty-plus cow Ju-Vindale Dairy in Cazenovia and interviewing Owner/Manager Vince Wagner widened perspective to the different styles of conventional dairy farming, and confirmed the consistency of dairy farmer challenges and vulnerabilities across farms of different size and type. Asking Wagner more targeted questions yielded further elaboration on the state of the industry. Finally, two subsequent return visits to Morrisville State College Dairy Complex and continued conversation with Bossard, as well as Dairy Science Dept. Chair Dr. Charles Mooney, added further insight into the specifics of previous discussion. Interviewing such experienced and knowledgeable dairy experts provided an incredibly comprehensive first-hand qualitative overview of the vulnerabilities of dairy farmers in Madison, as well as the adaptive measures that can be taken to mitigate these vulnerabilities.

Next, a literature review was used to compliment the qualitative information from the interviews. Examining scholarly publications on dairy production allowed for an increased understanding of many of the challenges discussed by Bossard and Wagner. Reviewing more quantitative publications offered insight into the severity of current and predicted climate change, as well as the levels of dairy production throughout time. Additionally, an academic framework of sustainability was used throughout the paper to analyze the research questions and define key ideas.

Finally, an econometric analysis of historic dairy productivity data was used to quantify the effects of certain weather changes on dairy production. This section involved data collection of historic milk production data from the USDA agricultural
census and the historic weather data from the NOAA weather database. Regressing milk production on weather data and fixing effects across six states and over seventy-nine years offered quantifiable estimations of the effect of changing weather factors on dairy production.

Results & Discussion

Vulnerability

Robert Kates argues, “becoming less vulnerable is a sign that a society is on a track to greater sustainability” (Kates, 2005, p. 14). As such, understanding the current vulnerabilities of conventional dairy farming in Madison County is a necessary first step towards understanding and improving the Industry’s sustainability. These vulnerabilities can be divided into the same three pillars with which we have compartmentalized sustainability: environmental vulnerabilities, economic vulnerabilities, and social vulnerabilities. The Madison County Agriculture and Farmland Protection plan outlines that “today, both agriculture and its cultural landscape is threatened by the loss of farms, the loss of important agricultural soils, and the loss of important open space” (Madison County Farmland Protection Board, 2005, p. 4). Through our dairy farm visits, interviews, and literature review, we have found that, like all other agriculture in Madison County, conventional dairy farms are exposed to all three types of vulnerabilities.

Environmental vulnerabilities relate primarily to the fragilities of feed crops and farmers’ ability to grow these crops as climate conditions change, as well as the sensitively of milk cows to heat stress, and the losses in milk productivity that accompany climate change. Farming of any sort is heavily reliant on local climate conditions, and dairy farming is no exception.
Dairy farmers like to produce as much of their own feed crops as possible. Doing so gives them cheaper and more flexible access to feed than purchasing from a third party would. Morrisville State College Dairy Complex Manager Shawn Bossard outlined the fact that, due to Madison’s relatively cheap land prices, there is almost no public market for tillable dairy farm land—as soon as a local farmer is even rumored to be selling land, other farmers immediately make offers, trying to boost their feed production capacity. Examining the Agricultural Census, we can see the steady increase in Madison County’s dairy farm acreage, even as farm number remains constant or declines, evidence of farmers’ desire to boost feed crop production, and subsequent land snatching (USDA, 2012). This means that Madison’s dairy farmers are on the whole increasing their capital exposure to crop production, and therein to the accompanying environmental vulnerabilities. Bossard recalls, “ever since we started growing crops [four years ago] we haven’t had a, what I would call, a typical season” in Madison County (personal interview, October 2014). He goes on to explain that an increase in torrential rain events has led to the erosion of much of the organic matter in his soil, rendering corn production (the typical dairy cow feed crop) impractical. Bossard outlines the lengths to which he has gone to fight against this erosion—strategies such as crop rotation, higher density planting, and experimenting with new crop types — saying “anything we can do to increase organic matter [remaining] in the fields, we’ve got to be doing” (personal interview, October 2014). All of these adaptations cost dairy farmers time and money, and none of the adaptations will be permanent amid a rapidly changing climate. Bossard is lucky to have extra land and a flexible budget with which to experiment (a perk of his dairy farm serving as an educational institution), luxuries most of Madison’s dairy
farmers do not have. As weather patterns in Madison continue to become more irregular, dairy farmers will face increased environmental vulnerabilities, and be forced to rethink their feed crop production. Furthermore, torrential rain patterns were shown to have hugely negative impacts on dairy productivity directly, in our regression analysis. These exposures will continue to grow on the very short two to five year time horizon, although their continuous change will perpetuate decades into the future.

Dairy cows prefer colder weather. Much of a dairy barn’s design is directed at maximizing ventilation and airflow to keep cows cool in warmer months. Warm weather upsets cows, as it disrupts eating, sleeping, and lactation habits. Dairy farmer Vince Wagner, who operates the Ju-Vindale Dairy in Cazenovia, saw great increases in cow productivity when he moved his operation from Meyerstown, Pennsylvania to its current location in Madison County. Meyerstown is about two hundred miles south of Madison, with an average annual temperature about six degrees warmer, according to USclimatedata.com. As such, Vince attributes much of his productivity gains to the colder climate, saying, “when it gets extremely hot, productivity drops ten, fifteen, or even twenty percent” (personal interview, November 2014). Our econometric look into the effect of heat on national milk production data shows a high level of correlation between temperature and cow productivity, further confirming Vince’s previous assertions (USDA, 2014). With the IPCC projecting temperature increases throughout the region over the next five to twenty years, the implications for dairy farming are obvious. Warming temperatures will hurt dairy cow productivity and further decrease the slim profit margins of many already struggling dairy farms. Farmers will need to devote more time and money to keeping their cows cool, and to dealing with the side effects (i.e.
increased sickness) of a warmer environment. These growing vulnerabilities will be felt in the middle to long term, as temperature increase accelerates over the five to twenty year time horizon.

Our nationwide econometric analysis of dairy cow milk production and weather data yielded the following regressions:

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<th>Explanatory Variables:</th>
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Notes: *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level. Robust Standard Errors in Parenthesis. Non Robust Standard Errors in Brackets.
Econometric analysis confirmed the common findings, and laments of farmers, that average dairy cow productivity drops with high temperature, and heat stress. We found that a one tenth of a degree Celsius increase from room temperature in average monthly temperature results in the loss of nearly 2 lbs of milk production per cow per month. This paper also demonstrated the harmful effects of torrential rain patterns. We found that a one day increase in the number of days per month with more than 0.5 inches of rain, holding total monthly rainfall constant, results in the loss of more than 8.5 lbs of milk production per cow per month. Since total monthly rainfall does not change, this previously undocumented effect shows that rainfall inconsistency (torrential rains followed by long dry periods) has an even greater negative impact on milk production than that of previously documented heat stresses. For a more comprehensive explanation, see the full paper in Appendix 1.

* * * * *

Economic vulnerabilities relate to the variable costs of intermediate inputs, small profit margins of dairy farms, and an inconsistent commodity price for milk. All of these facets add up to an industry wrought with uncertainty throughout every step of production: farmers are unsure of how much input goods will cost, how much production will cost, and how much revenue their end product will generate. While agriculture of any type faces some of these issues, dairy farming is particularly vulnerable.

Conventional dairy farming is very much a form of high input agriculture. The unstable nature of the cost of these inputs creates huge economic vulnerabilities within the industry. While dairy farmers in Madison County try to produce as much of their feed as possible, as outlined earlier in the paper, they are rarely able to produce all feed,
requiring the purchase of additional crops. Furthermore, farmers must purchase fertilizers and pesticides even for feed grown on-site. Other inputs include straw or wood shavings, used for cow bedding, as well as antibiotics and hormones used to keep cows healthy. All of these intermediate goods have variable prices about which farmers can never be certain. Arguably the most concerning input, however, is energy. Dairy farming is very energy intensive, requiring large amounts of energy to pump and store refrigerated milk, as well as to ventilate, heat, and cool farm facilities. In 2010, “energy expenses cost an average of $138 per cow per year,” making them “the eighth largest production cost on dairies, and… one of the fastest increasing” (Penn State Extension, 2011). As accelerating climate change continues to affect energy costs, and spur new energy regulation, prices are expected to continue to fluctuate, with a steeply upward trend. This leaves Madison’ County’s dairy farmers vulnerable to energy price shocks, or forces them to make costly energy saving investments. Shawn Bossard, for instance, raves about the Morrisville State College Dairy Complex’s methane biogas digester, from which his farm draws about eighty percent of its power. This steady source of cheap energy greatly reduces Bossard’s exposure to a form of vulnerability common throughout the industry, but the digester costs over five hundred thousand dollars to install—an enormous capital expenditure most dairy farms are incapable of making, even with state or federal grants. Other energy saving technologies exist, such as variable motor pumps, however they too are costly to install and provide minimal energy savings. Farmers in Madison County must continue to do as much as possible to reduce their reliance on intermediate goods with unstable prices, as many of these price fluctuations are set to worsen over the next five to ten years, as climate change worsens.
Milk prices have been relatively high recently—a good sign for dairy farmers this year. Unfortunately, these prices are not stable and are hard to predict. Though milk prices typically fluctuate on a four-year cycle, a booming milk export market has recently artificially inflated prices. Based on reports from the US Dairy Export Council, CNN reported that year over year milk exports to Southeast Asia are up thirty-nine percent, with exports to China alone up ninety-one percent (CNN Money, 2014). This huge uptick in milk demand has led to the high milk prices seen today, but many analysts fear that this export market may only increase milk price volatility moving forward. As a result, Madison’s dairy farmers who are currently benefitting in the short term from higher prices may be harmed in the long term, should they begin to count on such high prices persisting. It is difficult to say what policy or industrial changes in China or other Southeast Asian countries might affect demand for American milk, or how quickly those changes might impact milk prices in the U.S. All this means that a growing national milk export market may only create growing economic vulnerabilities for dairy farmers, as the international supply of milk grows causing domestic milk prices to become even more uncertain over the next five to ten years.

Given the unpredictability of input good prices, as well as final milk prices, dairy farmers are never very confident about where their profit margin may lie going into any given season. Add to this the inherent production level uncertainties associated with agriculture of any sort (caused by seasonal weather condition fluctuations, for instance), and it would seem that dairy farmers have almost no certainty about their farms’ bottom lines. One way many dairy farmers try to combat these economic vulnerabilities is through participation in dairy insurance programs, now newly updated and outlined under
the Agricultural Act of 2014. This new program allows dairy farmers to buy into more stable, guaranteed milk prices, insured by the US Department of Agriculture. The update to New York’s milk insurance program is more complicated than its predecessor, however, clouding the decision-making processes of farmers. Dairy Farmers now “have to make decisions on how much of their historical output or base to cover and at what margin level to elect coverage,” making the program’s benefit harder to assess (Insurance Journal, 2014). New York Senator Charles Schumer “cautioned that many small dairy farmers may not have the time or the resources to fully understand how to best use the new program before participating” (Insurance Journal, 2014). This means that certain smaller dairy farmers may misuse, or be left out altogether of this useful, and increasingly necessary, program. Many of Madison County’s dairy farmers fall within this category, meaning heightened economic vulnerability throughout the county.

*   *   *   *

Social vulnerabilities relate primarily to dairy farm consolidation, and the subsequent degradation of the dairy community. Though difficult to quantify, dairy farming has provided Madison County with a rich cultural and historical heritage, which is also vulnerable to changes brought on by the changing climate.

In the context of all of the previously discussed dairy farm vulnerabilities, one overall trend has emerged: the widespread consolidation of dairy farms nationwide. Vince Wagner outlines, “in 1976 when my wife and I started farming… there were two hundred thousand dairy farms in America….in 2014 there are forty seven thousand dairy farms in America. In thirty-eight years we’ve seen seventy-five percent of our dairy farms go out of business. To me that’s very sad.” This is not a downsize in the dairy
industry, but rather a consolidation effect: “census-enumerated dairy farms have decreased nationally for all sizes of operation except herds of 500 or more cows” (Cross, 2006, 1). Largely in response to decreasing profit margins, farms have been growing in size and decreasing in number in order to become better equipped to weather the effects of down years. The Madison County Agricultural and Farmland Protection Plan outlines, “the history, tradition, and economic impacts of the county’s dairy enterprise are worth noting,” as these farms have long had an impact on the overall culture of the county (Madison County Farmland Protection Board, 2005, p. 6). Many of Madison County’s dairy farmers are third, fourth, or even fifth generation farmers for whom dairy farming is not only a source of income, but also an engrained way of life. The loss of smaller dairy farms—particularly family operated dairies, has led to the serious degradation of this culture. Vince Wagner detailed the concept of land stewardship, championed by his father’s generation of dairy farmers, in which farmers fought to protect and improve the quality of their soils and livelihood overall. This approach to dairy farming is less visible in the conventional, industrial dairies toward which the industry has been trending. Furthermore, the remaining smaller scale, family operated dairy farms in the county are becoming ever more disadvantaged in competing with larger, commercialized farms. This steady consolidation means that many of the cherished social aspects of dairy farming—the culture and community farmers that Vince values so much—are becoming increasingly vulnerable to the threat of competition, acquisition, and consolidation.
With a better understanding of the vulnerabilities to which dairy farming in Madison County are exposed, we are now well primed to examine the ways in which we can decrease this exposure, and improve the sustainability of the industry as a whole.

**Adaptation**

Given the many economic, environmental, and social vulnerabilities of conventional dairy farming, adaptation is a key component for bulwarking the livelihoods of this industry against future climate stressors that may render such jobs and farms unprofitable in Madison County. While this concern specifically applies to the economic pillar of sustainability, its loss would inevitably result in that of the social and environmental pillars as well. Madison’s dairy farmers already feel some of the effects of climate change, such as inconsistent rain patterns and heat stress, but other effects will not be tangibly felt for many more years. Because of this, and because modifying the workings of a conventional dairy requires immense amounts of time, capital, and forward thinking due to the size and complexities of the operations, it is integral to assess and predict future needs in anticipation of change. From this anticipation stems the ability of the industry to adapt. In order to assess this ability to adapt, this paper has broken down adaptation into its two component parts, generic and impact specific adaptive capacities, as determined by the Intergovernmental Panel on Climate Change. After a brief assessment of conventional dairy’s capacity for adaptation, we will outline a regiment of adaptive measures that may help to thwart the negative impacts of climate change.

**Generic Adaptive Capacity**

Generic adaptive capacity, as the name implies, refers to general characteristics that affect the ability of all systems or industries to adapt overall. For conventional dairy
this includes primarily access to financial, human, and physical capital, as well as land. Historically, dairy farms have not benefited from access to free cash flow, plaguing the ability of many farmers to upgrade costly infrastructure and invest in adaptation. Shawn Bossard sheds light on exactly how tight dairy budgets run: Morrisville Dairy Complex generates $24.00 in average daily revenue per milking cow, but incurs $21.00 in average daily costs per cow. Of the more than five hundred cows at the complex, however, only about two hundred are milking on any given day, making profit margins incredibly thin. Vince Wagner reiterated similar struggles at his much smaller farm, confirming the consistency of these issues throughout conventional dairy farming of all types.

Further exacerbating the security and consistency of these already thin profit margins is the American dairy industry’s heavy reliance on the export market, previously enumerated in this paper. Potential harm from Chinese or other foreign dairy expansion decreases the generic adaptive capacity of the industry as a whole, as farmers may soon lose out on a major source of revenue. It is also important to note that the problems surrounding financial security of all conventional dairy farms is fairly similar regardless of the farm size. Ju-vindale Dairy sells their raw milk for approximately $4.00 per gallon even though it costs over $3.00 to produce, is prohibited from selling wholesale through stores, and must instead sell directly to the consumer on its premises. In fact, the profit margins are so thin that Morrisville Dairy Complex, for example, has consistently relied on government and college grants to aid its expansion and technological implementation, otherwise “we would have never been able to afford our bio digester”, claims Shawn Bossard. Unfortunately, smaller private dairy farms do not usually benefits from these
specific financial offerings, although they can participate in insurance and other programs that help prevent bankruptcy.

After access to capital, land is the most important determinant for generic adaptive capacity. Building a dairy farm from scratch requires immense capital investment upfront, often burdening farmers with debt. As such, many dairy farmers prefer to purchase existing dairy farms and convert them to their liking, as Vince Wagner did when he relocated to Madison County from Pennsylvania. This has made land suitable for dairy farming (along with milking parlors, stables, and other necessary facilities) relatively scarce. Therefore, land is an extremely important, and binding long-term asset: once a dairy farm has been established it does not make sense, nor is it often feasible to move the farm elsewhere. Thus, a dairy farm that finds itself on a precarious piece of land affected by climate change patterns, such as new flood zones or eroding soil quality, must confront the challenge rather than move away from it. Because of the inflexible lack of access to capital, and semi-permanent ties to land, it is easy to conclude that the dairy industry is ill suited to adapt to climate change with only its generic capacities.

**Impact Specific Adaptive Capacity**

Impact specific adaptive capacity involves unique tools or knowledge that an individual system or industry harnesses offering distinct adaptive abilities, as compared to other industries. Conventional dairy farming’s deep cultural ties and tight-knit community present valuable resources from which other agricultural sectors, and industries, do not necessarily benefit. Dairy farmers are particularly willing to work together. Milk cooperatives represent one of the most invaluable programs available to
dairy farmers, providing member farms with resources, expertise, and support. Dairy Farmers of America (DFA) is one of the largest milk cooperatives in the country with some of its 13,000 members hailing from Madison County. This organization strives to “unite their talents, leadership, markets and capital into a single, stronger cooperative better able to work for the dairy farmer” (www.dfamilk.com). While DFA seeks to create markets and facilitate transactions for the farms, other cooperatives such as National Milk Producers Federation aim to provide dairy farms with a voice in policy proposal and implementation.

Similar in nature and purpose to cooperatives are local conventions, essentially knowledge-sharing programs, which can serve as conduits for communicating different types of adaptive measures and strategies. Another type of program that has rapidly grown in popularity and adoption are dairy insurance programs, as earlier mentioned in this paper. One such “program is a kind of insurance that pays farmers when the difference between milk prices and feed prices shrinks to a certain level” (Journal Sentinel Staff, 2014). These types of mechanisms help to compensate for the financial factors contributing to low generic adaptive capacity for the dairy industry. Shawn Bossard believes this once nonexistent financial service has kept many dairy farms afloat as weather changes and feeds costs continue to experience unparalleled volatility, and he claims around thirty percent of farms participate in the programs now.

Many of the impact specific adaptive capacities benefiting the dairy industry deal with disseminating information from those who know to those who do not. This is extremely unique from many industries where secrecy and information protection is integral for success and competition. Therefore, a key distinction for farmers in the dairy
industry is their inclination and ability to work together rather than against each other, and succeed as a unified force rather that leave their success to chance. This characteristic is derived not so much from farmers’ desire to survive financially, but more so from the deep cultural heritage and traditions that bind farmers together. Cooperation is arguably the industry’s biggest strength. Thus, while weak generic adaptive capacity characterizes dairy farm’s financial abilities to adapt, strong impact specific adaptive capacity compensates for this disadvantage. Therefore, while adaptive recommendations are not limited to either category, many of the following adaptive measures are geared toward bolstering generic adaptive capacity in particular.

Adaptive Measures
Adaptive measures, distinct from the goal of policy proposals at the end of this paper, are tools or ideas that farmers can employ to decrease their vulnerability specifically to climate change and increase the capacity for adaptation should drastic change take root. Because the policy proposals target factors relating to generic adaptive capacity in an effort to elevate the financial standing of the whole industry, these measures focus on specific action farms can take to increase their individual standing. In addition, some of these measures inevitably compromise certain pillars of sustainability in favor of others, but they are objectively presented nonetheless to allow farmers to make their own decisions for what is morally appropriate.

One general trend that has occurred over the past few decades is a drop in the number of dairy farms throughout the country. According to Cross (2006), “The number of farms with milk cows in the United States has been declining steadily. Between 1992 and 2002, for example, it fell by 40.8 percent” (pg. 2) Intuitively, it seems this
consolidation results from technological changes that allow for exploitation of economies of scale; a three thousand-cow farm spends less on feed per cow than an eighty-cow farm because it buys in bulk and receives discounts. However, “confounding this issue is evidence that reductions in numbers and increases in average farm size are the result of changes more in relative factor prices than of technological change” (Weersink and Tauer, 1991, pg. 1140). Research by Weersink and Tauer published in the American Journal of Agricultural Economics suggests there is no causal relationship between a larger average herd size and productivity per cow (Weersink and Tauer, 1991, pg. 1138). However, their study does not dispel that costs associated with the maintenance of each cow are also the same, and leaves reason to believe that economies of scale still take effect. Therefore, to reduce feed costs and increase profits, farms can consolidate. Understanding the cultural detriments and the fact that many smaller scale dairy farmers oppose consolidation, however, quasi-consolidation seems a more attractive option. Separate small farms can cooperatively function as one large farm in certain respects (when purchasing input goods, and handling wastes for instance) but operate individually in other respects. For example, if Vince Wagner of Ju-Vindale Dairy partnered with other nearby dairy farms to coordinate feed purchases, these farms could leverage their collective economies of scale and receive cheaper input good prices, while remaining separate entities overall.

While the aforementioned recommendation does not deal with any specific environment but rather provides value in any setting for the dairy industry, some other measures should be taken to protect cows against uncertain weather events. For example, “studies tend to agree that...climate change would negatively impact livestock production
through decreases in weight gain, dairy output, and feed conversion efficiency” (Lewandrowski and Schimmelpfennig, 1999, 43). To prevent this change from shrinking profit margins even further, Vince Wagner employs simple, customizable ventilation measures on his farm to keep his cows cool. For example, upon purchasing his farm in Cazenovia, Wagner adapted the barn by lifting the roof six inches higher and creating his own pulley system to control ventilation. Mr. Wagner accounted for minute details too, such as directing the vents down the sides of the barn, where the cow’s heads are, in order to cool them more efficiently. To aid the ventilation system further, Mr. Wagner installed two industrial-sized fans into large windows aimed in the same direction as the vents. While the latter adaption is very common on dairy farms, the former is unique and innovative, and other farmers may too be able to apply this theory to their barns.

In addition to stress placed on cows from climate change, the phenomenon will affect farms in other ways, especially for crop production. Morrisville Dairy Complex strengthened its independence from feed suppliers when it decided to grow its own feed. However, this decision has placed a new burden on Shawn Bossard and his workers: to grow crops consistently and reliably regardless of climate conditions. Bossard notes, “[we] haven’t seen a steady rain ever since we decided to start growing our own feed” (Personal interview, 2014). He explains it is imperative to “weather-proof” the soil against harsh and sporadic rains in order to maintain steady feed production. Unfortunately he has not yet determined a way to do so, although he is experimenting with different types and strains of crops. Farms in a similar situation can follow suit by seeing what crops grow most reliably in their own soil, and also rotating crops seasonally
or yearly. Most importantly, to prevent soil degradation, farmers should try to rotate cropland used in alternating years, allowing soils to recover.

In addition to these basic fundamental farming techniques, farmers can invest additional capital in implementing more sophisticated irrigation systems that provide consistent water for the crops regardless of the actual weather. Another promising technology that could evolve over the coming years is hydroponics systems that allow farmers to grow crops without soil. This could theoretically eliminate all dependency on weather conditions; however, the scale of these systems has not yet been proven to be of use for dairy farms and they most certainly would be adopted by commercial-size farms rather than ones like Ju-vindale because of the sheer cost of purchase. Furthermore, once a cost-effective solution is devised, numerous conventions and cooperatives should collude to quickly promulgate the fix among their member farms.

Lastly, bio-digesters represent an already existing technology that promotes both environmental and economic sustainability on dairy farms. Simply speaking, a bio-digester uses waste from cows to generate electricity for the farm. Therefore, it creates a more sanitary farm, dilutes methane excretion, and reduced energy costs for farms. Bio-digesters are available for many different farm sizes, but still represent a financial luxury.

**Policy Proposals**

Distinct from adaptive measures in that they are devised and implemented by policy officials rather than farmers themselves, policy proposals aim to confront and overcome obstacles out of the farmers’ direct control specifically for Madison County. As has been mentioned, a root cause of much uncertainty for the dairy industry stems from financial troubles. Further, though many farmers do receive a secondary or college education,
typically their studies address farming techniques rather than financial management or accounting. Douglas Jackson-Smith and David Trechter researched the impact of financial management training on dairy farm production, operating under the assumption that cows are sensitive to different management techniques that may be influenced by financial acumen (Jackson-Smith and Trechter, 2004).

Although their study samples Wisconsin dairies, it is reasonable to extrapolate their findings to Madison County. They find that “while the data suggests that most Wisconsin dairy farms keep some financial records, almost half fail to use them for anything other than tax preparation” (Jackson-Smith and Trechter, 2004). Furthermore, most farmers were unable to identify the meanings for many key farm financial management (FFM) concepts. This suggests that a lack of understanding may prevent farmers from applying many FFM concepts, and therefore the prices of raw inputs and milk, while volatile, are not completely free from manipulation and management. That is, the negative effects of weather variables on cow productivity are not totally random and uncontrollable. If this is so, the economic viability and generic adaptive capacity of the dairy industry may be increased with proper education and training on financial management practices; the Jackson-Smith and Trechter article suggests a “link between a deeper understanding of financial concepts and greater financial returns.”

Therefore, policy makers in Madison County can aid farmers in managing their farms and increase their adaptive capacity by providing financial training programs and seminars. Such programs ought to be provided for free, and can leverage finance and accounting professors from surrounding universities. The regiment of the program will be determined by the county, of course, but a weekly meeting supplemented with
appropriate literature will likely serve as a good starting point to gauge the effectiveness of the program. Milk cooperatives should also consider sponsoring this style of events, for not only will this type of program improve the economic standing of dairy farms, but it will also increase cultural ties further by constantly bringing dairy farmers together. This in turn generates more knowledge sharing among the industry players, thus indirectly strengthening impact specific adaptive capacity as well.

While the first policy proposal assists with farm management, the second seeks to bridge the financial gap that prevents farmers from adopting more sustainable technologies, such as the bio-digester seen at the Morrisville Dairy Complex. This type of equipment requires an enormous initial capital investment, $500,000 in the case of Morrisville’s, but the energy savings and sustainability are unparalleled. For example, the Morrisville Dairy Complex now generates 80% of the electricity needed to run the farm directly with its bio-digester, and at the same time reuses cow waste in a useful way rather than simply discarding it. The Morrisville Dairy Complex benefits from its primary function as an academic institution and this has increased access to credit to build new technologies. Unfortunately, as outlined in the generic adaptive capacity section, most private farms cannot afford these capital-intensive investments. Therefore, we recommend the county ease financial stress through a combination of tax breaks, low-interest financing, and grants so dairy farmers can adapt their farms more cheaply. While implementing a bio-digester on every dairy farm may be an unattainable goal, alleviating financial strain will help free up disposable income so that farms incorporate cheaper, yet equally sustainable, and technologies, such as solar panels.
Conclusion
The dairy industry represents a vital component of Madison County. It provides jobs and livelihoods, a rich cultural heritage, and, most importantly, milk. Though the viability of dairy farming is at risk of being disrupted by widespread climate change manifestations—in particular temperature increases and extreme rainfall events. Current literature, personal interviews, and new data analysis all support the claim that dairy production will be severely compromised if certain weather changes take place. Furthermore, while the industry benefits from some specific adaptive mechanisms, such as insurance programs and milk cooperatives, farms lack a solid monetary base to finance adaptations on their own land. Installing ventilation systems, as exemplified by Ju-Vindale Dairy, is one cost-effective way farmers can cool their cows in warmer months; farmers can also attempt to grow more crops on-site to reduce the cost of feed inputs, although sporadic rainfall has made this adaptation increasingly complicated. To alleviate these strains and buttress the Madison County dairy industry, policy makers can implement a two-pronged approach: first, providing financial management training programs will likely result in greater financial returns for farmers. Second, an amalgamation of tax breaks, low-interest financing, and grant programs will complement the increased financial returns seen from the first policy, and ultimately provide farmers with much more available capital to use for adaptation techniques. Overall, dairy is an integral component not only for Madison County, but for the global economy. Difficulties lie ahead, but a well-coordinated effort on the part of dairy farmers and policy makers alike can gently guide the industry through impending climate change whilst maintaining the sustainability of the sector.
Bibliography


Appendix 1: Econometric Results

Introduction & Literature Review
Technological development over the last seventy-nine years has resulted in unilateral increases in farm productivity in all aspects of the agricultural sector. The dairy industry in particular has seen milk production rise from about 300 pounds per cow to more than 2,000 pounds depending on the year and location (NASS, 2014). However, simply because production has risen over time does not mean farmers consistently milk their cows for all their worth. A growing body of literature, supplemented with personal accounts of farmers themselves, suggests that cows produce less milk in hot weather compared with cooler temperatures. The United States Department of Agriculture estimates that heat stress lowered annual milk production for the average dairy by $39,000 in 2010, totaling to $1.2 billion in lost output for the industry as a whole (USDA, 2014). This specific article helped target our research by providing insight into what variables the USDA believes are most responsible for decreased productivity, highlighting temperature stress as the major explanatory variable, outweighing other factors such as precipitation changes. The author also does a nice job of placing the decreased productivity as a result of climate change, into an economic context allowing our interpretations to extend to the economic viability of the dairy industry. A relatively large body of literature already exists under the assumption that a negative relationship relates heat stress to cow productivity, and many articles therefore question the dairy industry’s economic viability in the face of continuing climate change (Von Keyserling et al. 2013).

On the other hand, some critics optimistically posit that the effects of climate factors on dairy productivity are unclear, and have been overblown. Anthony Berman, for instance, argues that adaptive breeding has allowed cows to genetically adapt to warmer weather, eliminating most of the ill effects of temperature increases (2010). If selective breeding could yield specialized cows optimally fit to their environment, many of the climate factors we have identified as explanatory variables could become irrelevant (Berman 2010). Whether such breeding can keep up with the rapidly changing climate, however, remains unclear. Considering these controversial and interesting perspectives helped us understand why some particular aspects of our model may not perfectly align with our theory. This in turn encouraged a broadened perspective and more creative thinking, causing us to consider some possible omitted variables, such as worker productivity, that may skew the relationship between weather variables and productivity.

When loss of productivity is placed in the context of the dairy industry overall, any small variance in temperature suddenly has a very large impact on farm profitability. The Morrisville State College Dairy Complex in Morrisville, NY reports an average profit margin of $3 per milking cow per day on its five-hundred cow farm, though not all cows milk at once. Exacerbating the financial situation further, the USDA reports average per farm production expenses increased 69%, from $257,104 to $435,610, in the years from 2002 through 2007 (2012). These very narrow profit margins characterize all

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1 Vince Wagner, owner and operator of Ju-Vindale Dairy in Cazenovia, NY, claimed that “when it gets extremely hot, productivity drops ten, fifteen, or even twenty percent” in a recent interview.
2 Farm manager Shawn Bossard outlined in a recent interview.
farms, large and small, within the dairy industry, suggesting that slight changes in milk production could catastrophically affect the profitability of this key agricultural sector.

Understanding the relationship between dairy production and weather variables is paramount in comprehending how impending climate change will affect the industry over the coming decades. It important to understand the accuracy of current claims and their perceived effects. Is there a correlation between increased heat stress and decreased productivity? If so, is it meaningful and to what degree can we expect to see an effect? Do other climate factors similarly affect milk production? This paper seeks to isolate the effect of certain weather variables on milk cow productivity in an effort to further analyze how economically viable dairy farms in the face of climate change may be in the coming decades. To draw conclusions about the above relationships, Section I provides insight into the data collection process; Section II articulates the estimation framework used; Section III discusses regression results and analysis; and Section IV draws relevant conclusions.

I. Data Collection

The data used in the following regressions comes from two main sources. Agricultural data on monthly milk production was drawn from the National Agricultural Statistics Service (NOAA)’s public database. This service offers state wide monthly milk production numbers on gross and per cow basis, as well as milk price per gallon. In an effort to capture maximum variance in weather variables, and maximum sample size, we selected six of the ten biggest dairy producing states across various climatic regions in the United States: Michigan, New York, Idaho, Texas, Wisconsin, and Pennsylvania. We intentionally excluded certain geographically diverse states such as California, because different parts of the state experience different climatic conditions, rendering average weather statistics inaccurate explanatory variables of state-wide productivity. For each state we compiled gross milk production in lbs, per cow milk production in lbs, and milk price in US dollars throughout seventy-nine years, dating back to 1935.

Average monthly statewide weather data was derived from The National Oceanic and Atmospheric Administration (NOAA)’s public database. Though NOAA does not directly report such state-wide statistics, we compiled the data most representative of these figures. By selecting individual weather stations located near the geographic center of each state, at average altitude, and away from any local weather-influencing phenomena (i.e. lakes, mountains, large cities, etc.), we compiled weather data representative of state wide averages. NOAA’s weather variables can be divided into three main descriptive categories: computed, precipitation, and temperature data. The research leverages eighteen weather variables in total, and the table below summarizes their abbreviations and meanings. Variables eventually used in our regressions are marked with an asterisk.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLDD*</td>
<td>Cooling degree days. These use a 65 degree Fahrenheit base and given as a monthly total.</td>
</tr>
<tr>
<td>HTDD</td>
<td>Heating degree days. These use a 65 degree Fahrenheit base and are given as a monthly total.</td>
</tr>
<tr>
<td>DT00</td>
<td>Number days in month with minimum temperature less than or equal to 0.0 F</td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>DT32</td>
<td>Number days in month with minimum temperature less than or equal to 32.0 F</td>
</tr>
<tr>
<td>DT90*</td>
<td>Number days in month with maximum temperature greater than or equal to 90.0 F</td>
</tr>
<tr>
<td>DX32</td>
<td>Number days in month with maximum temperature less than or equal to 32.0 F</td>
</tr>
<tr>
<td>DP10</td>
<td>Number of days in month with greater than or equal to 1.0 inch of precipitation</td>
</tr>
<tr>
<td>DP05*</td>
<td>Number of days in month with greater than or equal to 0.5 inch of precipitation</td>
</tr>
<tr>
<td>DP01</td>
<td>Number of days in month with greater than or equal to 0.1 inch of precipitation</td>
</tr>
<tr>
<td>EXMP*</td>
<td>Extreme maximum daily precipitation total within month (tenths of mm precision)</td>
</tr>
<tr>
<td>MXSD*</td>
<td>Maximum snow depth reported during month (mm)</td>
</tr>
<tr>
<td>TPCP*</td>
<td>Total precipitation amount for the month (tenths of mm precision)</td>
</tr>
<tr>
<td>TSNW*</td>
<td>Total snow fall amount for the month (mm)</td>
</tr>
<tr>
<td>EMNT</td>
<td>Extreme minimum temperature in tenths of degrees Celsius</td>
</tr>
<tr>
<td>EMXT</td>
<td>Extreme maximum temperature in tenths of degrees Celsius</td>
</tr>
<tr>
<td>MMNT</td>
<td>Monthly mean minimum temperature in tenths of degrees Celsius</td>
</tr>
<tr>
<td>MMXT</td>
<td>Monthly mean maximum temperature in tenths of degrees Celsius</td>
</tr>
<tr>
<td>MNTM*</td>
<td>Monthly mean temperature in tenths of degrees Celsius</td>
</tr>
</tbody>
</table>

After aligning monthly milk production with monthly weather variables by state, the complete data set represented 101,946 data points in 5,623 unique observations across six different states between 1935 and 2013.

II. Framework Estimation

To determine the effect of different weather variables on cow productivity, we begin by regressing cow production per head on eight key weather variables based on our theoretical framework. Although NOAA data yielded eighteen separate weather variables, including all eighteen would have produced a high degree of multicollinearity and contradicted our theoretical framework. Selecting our eventual explanatory variables meant accounting for both of these factors.

CLDD and HTDD both effectively measure temperature as a function of energy demand, so including both would create multicollinearity. As such we included CLDD, as it measures total degree days above 65 F, an indicator of potential heat stress levels for dairy cows.

DT00, DT32, DT90 and DX32 all effectively measure the monthly frequency of especially hot and cold days as defined by daily temperature maximums and minimums. As such, incorporating more than one of these variables would have produced multicollinearity. We opted to include only DT90 because it measures frequency of hot daily maximums, likely indicative of heat stress on cows.

Likewise, DP10, DP05, and DP01 all effectively measure the monthly frequency of precipitous days. Again, incorporating more than one of these variables would have produced multicollinearity. We opted to include DP05 because it measures medium to
major level precipitation events, but also has a greater variance than DP10 (which rarely exceeded 2 throughout our data set). This variable should be indicative of the effect of more torrential rainstorms on dairy events.

EMXP and MXSD represent maximum daily rainfall and snowfall, while TPCP and TSNW measure total monthly rainfall and snowfall respectively. There should not be multicollinearity between these values. We opted to include all of these variables because literature had told us little about their expected effects, and because holding them each constant brought added value to the interpretation of our other explanatory variables.

Finally, EMNT EMXT, MMNT, MMXT, MMNT all represent measurements of monthly temperature, so including them all would once again create multicollinearity. We opted to include MNTM because we felt it was the best overall measure of heat stress on cows. The following model represents the base regression for this study:

\[ C_t = \beta_0 + \beta_1 CLDD_t + \beta_2 DT90_t + \beta_3 DP05_t + \beta_4 EMXP_t + \beta_5 MXSD_t + \beta_6 TPCP_t + \beta_7 TSNW_t + \beta_8 MNTM_t + \mu_t \]

\( C \) represents state wide monthly milk production per cow and \( \mu \) is an error term. Lastly, after much consideration, we left milk price out of the right hand side of the equation, as we determined that milk price is received after production is complete, and is in many ways determined by production levels, not the other way around. This model was run as is, with year fixed effects, and with year and month fixed effects.

Our second estimated model is identical to model 1, but adds a new squared term explanatory variable:

\[ C_t = \beta_0 + \beta_1 CLDD_t + \beta_2 CLDD_{t-1} + \beta_3 DT90_t + \beta_4 DT90_{t-1} + \beta_5 EMXP_t + \beta_6 EMXP_{t-1} + \beta_7 MXSD_t + \beta_8 MXSD_{t-1} + \beta_9 TPCP_t + \beta_{10} TPCP_{t-1} + \beta_7 TSNW_t + \beta_8 TSNW_{t-1} + \beta_9 MNTM_t + \beta_{10} MNTM_{t-1} + \mu_t \]

\( MNTM_{sq} \) represents a squared nonlinearity term for \( MNTM \) in an effort to account for how the effect of \( MNTM \) on \( C \) changes based on the magnitude of \( MNTM \). Theory suggests that a one degree average temperature change at low temperature, say from 46F to 47F, may have less of an effect than the same increase at high temperature, say from 88F to 89F, when heat stress is more apparent. Again, a combination of year and month fixed effects are included.

Our third model is identical to model 2, but with added lag terms of each of the previously statistically significant weather explanatory variables:

\[ C_t = \beta_0 + \beta_1 CLDD_t + \beta_2 CLDD_{t-1} + \beta_3 DT90_t + \beta_4 DT90_{t-1} + \beta_5 EMXP_t + \beta_6 EMXP_{t-1} + \beta_7 MXSD_t + \beta_8 MXSD_{t-1} + \beta_9 TPCP_t + \beta_{10} TPCP_{t-1} + \beta_7 TSNW_t + \beta_8 TSNW_{t-1} + \beta_9 MNTM_t + \beta_{10} MNTM_{t-1} + \beta_7 MNTM_{sq_t} + \beta_{10} MNTM_{sq_{t-1}} + \mu_t \]

These lagged weather explanatory variables account for the lasting effect of weather factors carrying over into the new month. These variables were included to align with our theory: we believe weather variables impact milk productivity with immediate effects (i.e. heat stress, cow exercise levels) as well as more long term effects that carry over between months (i.e. cow sickness, lactation cycles). The lagged variables account for these long term effects.

**III. Regression Results and Analysis**
Five regressions were estimated as we progressed towards our final model, as seen above. The first model, our base model, is simply our dependent variable, monthly milk production per cow regressed on each of our eight weather explanatory variables. This model, as uses robust standard errors, since an earlier White Test returned a p-value = 6.9e-12, leading us to conclude that the data likely supports the fact that this motel is heteroskedastic. The model shows five highly statistically significant explanatory variables, however returned an $R^2$ of only 0.0293, meaning that only about three percent of the total variation in our dependent variable has been accounted for by the systematic portion of our regression equation. This is unsurprising, as the model accounts only for weather based explanatory variables, and not the many other factors that might play into milk production levels, such as farm technology or milk prices.

In order to account many of these omitted variables, our second model fixed time effects on a yearly basis. This allows any changes in dairy technology, production practices, or even cow evolution affecting production per cow to be held constant.
throughout our seventy-nine year observation period. An F-Test of joint significance of these newly added year dummies returned a test statistic of 878, leading us to conclude that the data likely supports the joint significance of these year fixed effects. Predictably, adding so many year dummies led to massive increase in $R^2$, to 0.9458. This model also saw a sixth explanatory variable become highly statistically significant. Examining the estimators more closely, we noted that CLDD and MNTM counter intuitively showed opposite signs, despite both variables representing differing techniques of measuring heat. It seemed improbable that cooling degree days might have a negative correlation with our dependent variable, while average monthly temperature had a positive correlation, holding all other variables constant. A return to theory led us to discover another omitted variable: though we had fixed effects by year, we had allowed for time variation between months within each year, and subsequently omitted seasonal variables affecting milk production per cow.

To account for the confounding effects of seasonal factors affecting dairy production, our third model fixed time effects on a monthly basis, as well as a yearly basis. An F-Test of joint significance of these newly added month dummies returned a test statistic of 2.32, leading us to conclude that the data likely supports the joint significance of these month fixed effects. Once again, adding these month dummies led to the predictable increase of $R^2$, to 0.9681. The same six explanatory variables remained statistically significant, though two variables, EMXP and TPCP became slightly less so. Here, a RESE Test returned a test statistic of 52.34 and p-value of 0.0000, leading us to conclude that we were again omitting variables—this time of the higher order or interaction variety.

Another return to theory led us to hypothesize that the effect of a one unit increase in mean monthly temperature likely depends on the magnitude of that temperature, prompting us to include MNTMsq in our fourth regression. Adding the additional explanatory variable once again led to predictable increase in $R^2$, to 0.9687. This model maintained the high statistical significance of all previously significant variables besides TPCP (now statistically insignificant), and showed high statistical significance of MNTMsq.

A final return to theory tells us that the effects of weather patterns on dairy production may well carry over from month to month, as cow health and lactation cycles can extend beyond one month. As such, our fifth and final model incorporates one month lag terms on each of the previously statistically significant explanatory variables, accounting for these carry over effects. Adding these lag terms once again led to a predictable increase in $R^2$, this time to 0.9690. This final model returned CLDD, CLDD$^{-1}$, DP05$^{-1}$ and DP05, MXSD, MNTM, and MNTMt, MNTMsq, and MNTMsq$^{-1}$ as statistically significant at either the 1 or 5 percent level. Notably insignificant were EMXP along with its lag term EMXP$^{-1}$, as well as MXSD$^{-1}$.

When interpreting this final model, it is important to mind the true purpose of this paper. Specifically, we seek to understand the effects of climate change on dairy

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3 Since MNTM is an average monthly value, it makes sense that one added unit would have differing effect on the dependent variable depending on the magnitude. This is in contrast to all other variables which represent either monthly totals (i.e. cooling degree days, days with max. temperature over 90, total monthly precipitation, etc.), or monthly extremes (i.e. max. snow depth, max. daily precipitation, etc.), for which linear coefficients are ample. As such, we squared only the MNTM value.
production. As such, rather than examining explanatory variables and their lags separately, it makes sense to look only at the permanent effects (variable + lagged variable) for each. These can be found in the following table, denoted as VARPE:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLDDPE</td>
<td>-.013241</td>
<td>[.009037]</td>
</tr>
<tr>
<td>DP05PE</td>
<td>-8.666743***</td>
<td>[2.108976]</td>
</tr>
<tr>
<td>MXSDPE</td>
<td>.0335444***</td>
<td>[.0165709]</td>
</tr>
<tr>
<td>MNTMPE</td>
<td>-.475269***</td>
<td>[.0525759]</td>
</tr>
<tr>
<td>MNTMsqPE</td>
<td>-.0032621***</td>
<td>[.000403]</td>
</tr>
</tbody>
</table>

Notes: *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level. Non Robust Standard Errors in Brackets. MXSD permanent effect excludes lagged term due to insignificance.

Here, we see that CLDD has now lost significance, and so we turn our focus to the remaining four explanatory variables. While we care about the magnitude of DP05, MNTM, and MNTMsq, we merely sought to hold MXSD constant, and will therefore forgo interpretation of this variable beyond saying that it is statistically significant at the 5 percent level, and has a small positive correlation with milk production. \( \beta_{DP05PE}, \) or \( \beta_{DP05t} + \beta_{DP05_{t-1}} = -8.666743 \) with a p-value of 0.000. Furthermore, we can be confident that 95 percent of the time the interval -4.533227 to -12.80026 will contain the actual parameter. This tells us that every one day increase in the number of days per month with at least 0.5 inches of rain is associated with an average decrease of 8.67 lbs of monthly milk production per cow, holding all other variables (including total monthly precipitation) constant. This means that increased torrential rain patterns (i.e. fewer, harder storms with unchanging total monthly precipitation) tremendously hurts milk production per cow.

\( \beta_{MNTMPE}, \) or \( \beta_{MNTM_t} + \beta_{MNTM_{t-1}} = -.475269 \) with a p-value of 0.000. This parameter tells us that a one tenth degree Celsius increase in mean monthly temperature from 0 degrees Celsius (so that MNTMsq=0) is associated with an average decrease of 0.475 lbs of monthly milk production per cow, holding all other variables constant. Furthermore, we can be confident that 95 percent of the time the interval -.3722222 to -.5783158 will contain the actual parameter. \( \beta_{MNTMsqPE}, \) or \( \beta_{MNTM_{sqt1}} + \beta_{MNTM_{sqt-1}} = .0032621 \) with a p-value of 0.000. This negative sign tells us that as temperature level increases, monthly milk production per cow decreases at an increasingly negative rate, confirming our theory. To quantify the overall associated effect of a one tenth degree Celsius temperature increase on average monthly milk production per cow, we must combine \( \beta_{MNTMPE} \) and \( \beta_{MNTMsqPE}. \) Doing so simplifies down to the formula \( \beta_{MNTMPE} + 2\beta_{MNTMsqPE} \) (Temp in tenths of degrees Celsius). A one tenth degree increase in average monthly temperature from room temperature (20 Celsius, or 200 tenths), for instance, would look like -.475269 +2(-.0032621)(200)= -1.780109. This means that the increase of MMNT from 200 to 201 tenths of a degree Celsius is associated with an average decrease of 1.78 lbs in monthly milk production per cow. Although the quantity of milk production lost due to mean monthly temperature change depends on the magnitude of initial temperature, analysis of the relationship as a whole yields one conclusion: a warming climate will continue to negatively impact milk production, and the magnitude of these negative impacts will increase with temperature.

IV. Conclusion & Areas for Further Research

Our national level analysis of the effects of changing climate factors on milk productivity offered insight into the many links between weather and one of America’s leading agricultural sectors: the dairy industry. We found that dairy farms in America typically
operate with razor thin margins, making long term viability—let alone profitability—a challenge. Looking into the affects of temperature and precipitation factors on milk productivity produced some daunting results. Our paper found that temperature and precipitation factors both have statistically and economically significant effects on milk production, and that current climate change trends will bring about substantially decreased cow productivity. The IPCC predicts that climate change in the US will be characterized by an increase in temperatures and weather pattern extremes over the next century. Our paper proves that along with this change will come loss in dairy farm productivity, and subsequently, profitability.

Specifically, this paper confirmed the popular theory that average dairy cow productivity drops with high temperature, and heat stress. We found that a one tenth of a degree Celsius increase from room temperature in average monthly temperature results in the loss of nearly 2 lbs of milk production per cow per month. This paper also demonstrated the harmful effects of torrential rain patterns. We found that a one day increase in the number of days per month with more than 0.5 inches of rain, holding total monthly rainfall constant, results in the loss of more than 8.5 lbs of milk production per cow per month. Since total monthly rainfall does not change, this previously undocumented effect shows that rainfall inconsistency (torrential rains followed by long dry periods) has an even greater negative impact on milk production than that of previously documented heat stresses.

Further research ought to explore the reasons behind this surprising discovery—perhaps torrential rainstorms lead to more frequent transmission of disease, inconsistent temperatures affecting cow physiology, or other unknown factors. This paper could also be expanded upon and paired with regressions of weather data on milk price, adding further understanding and weight to the economic viability of dairy farming. And perhaps most importantly, research should focus on how the dairy industry may mitigate these effects, and adapt their practices to prepare for impending climate change with minimal cost.

Bibliography:


Appendix 1: Code for reduplication of results in STATA

use "Z:\Econ375C_114\Chandler Keller\Dairy Metrics.dta"
reg milkprodpercow cldd DT90 DP05 EMXP MXSD TPCP TSNW MNTM
whitetst
tabulate Year, generate(yr_)
tabulate month, generate(month_)
tabulate State, generate(st_)
reg milkprodpercow cldd DT90 DP05 EMXP MXSD TPCP TSNW MMXT yr_*
reg milkprodpercow cldd DT90 DP05 EMXP MXSD TPCP TSNW MMXT yr_* month_*
ovtst
gen MNTMsq= MNTM* MNTM
reg milkprodpercow cldd DT90 DP05 EMXP MXSD TPCP TSNW MNTM MNTMsq yr_* month_*
gen monthnum=1
replace monthnum=1 if month_7==1
replace monthnum=2 if month_4==1
replace monthnum=3 if month_8==1
replace monthnum=4 if month_1==1
replace monthnum=5 if month_9==1
replace monthnum=6 if month_7==1
replace monthnum=7 if month_6==1
replace monthnum=8 if month_2==1
replace monthnum=9 if month_12==1
replace monthnum=10 if month_11==1
replace monthnum=11 if month_10==1
replace monthnum=12 if month_3==1
gen yrnum= Year-1935
gen totalmonthnum=monthnum+yrnum*12
xtset StateANSI totalmonthnum
xtreg milkprodpercow cldd l.cldd DT90 DP05 l.DP05 EMXP l.EMXP MXSD l.MXSD TPCP l.TPCP TSNW l.TSNW MNTM l.MNTM MNTMsq l. MNTMsq yr_* month_*
lincom cldd+l.cldd
lincom DP05+l.DP05
lincom MXSD+l.MXSD
lincom MNTM+1.MNTM
lincom MNTMsq+1.MNTMsq