THI Application to Insuring Against Heat Stress in Dairy Cows

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Tulsa, Oklahoma, February 18, 2004

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Abstract: Heat stress is associated with reduced milk production in dairy cows. Insurance instruments based on an index of ambient temperature and relative humidity measured at Macon, Georgia and Tallahassee, Florida are shown to reduce net revenue risk for a representative farm in south-central Georgia.

Key words: risk management, THI, weather derivatives, revenue variance reduction

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Background and objective

Recent years have witnessed an increasing discussion about weather-based derivatives as mechanisms for sharing risks due to weather fluctuations. Weather derivatives are used to hedge the risk of weather-related losses. Applications were initially widespread among natural gas, oil, and electricity sectors. In early 1997 the energy sector first used temperature-based derivatives to hedge their risk of unpredictable temperature change. Heating Oil Partners (HOP), for example, was involved in an annual program of managing unpredictable revenue losses due to abnormally warm winters causing reduced demand for oil (Forrest). Those weather derivative contracts were sold in over-the-counter (OTC) markets. A contract could be tailored to satisfy different needs of the buyers.

In the fall of 1999, the Chicago Mercantile Exchange listed futures contracts on heating and cooling degree-days for a number of U.S. cities. The effects of El Nino and La Nina phenomena have further spurred the development of weather derivatives.

Although the initial applications of weather derivatives were mostly in the energy sector, such products are increasingly being discussed for agricultural insurance purposes. Many agricultural production enterprises are very sensitive to weather conditions. Common examples of weather-related risks are extremes of rainfall and temperature.

In the U.S., the Federal Crop Insurance Program facilitates the offer of insurance products that protect crop farmers against many weather-related risks. However, the program has struggled with problems such as moral hazard and adverse selection. In addition, large federal subsidies have been required to overcome problems with low participation. Though the Federal Crop Insurance Program has pilot-tested products that protect against livestock price risk, there are currently no federally-faciliated products that protect against livestock production risks.

Livestock producers, however, are also exposed to weather-related risks. Extreme heat or cold can cause death losses or, for confinement operations, large expenditures for cooling or heating (Martin, Barnett and Coble).

Weather derivative contracts pay indemnities contingent on the occurrence of a specific weather event (Turvey). Weather derivatives could conceivably provide risk protection for agricultural producers if the weather events specified in the contract are correlated with production shortfalls. However, unlike conventional insurance products, the indemnity on weather derivatives is not directly tied to realized farm-level production. In this sense, weather derivatives are similar to the area-based Group Risk Plan (GRP) and Group Risk Income Protection (GRIP) insurance products offered under the Federal Crop Insurance Program.

Long time-series of weather data are available over the internet from the National Climate Data Center (NCDC). These data have been collected from many weather stations across the U.S. that are associated with the National Oceanic and Atmospheric Administration (NOAA). Using these data one can construct objective and transparent weather derivative indexes that cannot be manipulated by the derivative purchasers. Since indemnities are based strictly on the realized value of the specified weather variable measured at the weather station, there is no need for purchaser-specific loss adjustment. This greatly reduces transaction costs relative to conventional insurance products. Further, since the data used to construct the weather derivative are widely available, there are no information asymmetry problems such as adverse selection and moral hazard.

Since weather derivatives are typically settled based on the realization of the weather phenomenon, at a given weather station, agricultural purchasers of weather derivatives would be exposed to some degree of geographical basis risk. This basis risk reflects the fact that the extreme weather event may occur at the farm though not at the weather station. In this case, the farm would receive no indemnity to offset losses associated with the extreme weather event. Of course the opposite is also true. The extreme weather event may occur at the weather station though not at the farm. In this case, an indemnity would be received even though no loss occurred. Agricultural purchasers of weather derivatives may be able to reduce their exposure to geographical basis risk by spreading their risk protection across derivatives based on several surrounding weather stations (Martin, Barnett and Coble).

This study proposes a unique temperature humidity index (THI) weather insurance instrument to protect against the risk of reduced milk production on dairy farms due to unusually hot and/or humid weather conditions. While conceptually equivalent to a weather derivative, we use the term weather "insurance" because the instrument would likely be sold through traditional insurance channels rather than financial exchanges. The study establishes a methodology for designing and pricing THI insurance. Specifically, the study:

1) Develops prototype index-based weather insurance instruments to protect against production, and hence revenue, risk faced by dairy producers in south-central Georgia;
2) Develops break-even premium rates for the prototype insurance instruments; and,
3) Assesses the feasibility of the prototype insurance instruments by comparing net revenue variability, with and without purchase of the insurance instruments on a representative south-central Georgia dairy farm.

Literature Review

Martin, Coble and Barnett investigated using precipitation insurance to protect against cotton yield and quality losses due to excess late-season precipitation in the delta region of

Mississippi. They assumed an insurance instrument where both rating and loss-adjusting would be based on precipitation measured at the nearest official government weather station rather than at the farm. They found that, in that particular context, precipitation insurance instruments could provide effective risk protection even when the insurance instrument was based on weather stations as far as 30 miles away.

Turvey examined the economics and pricing of weather derivatives in Ontario and proposed that weather derivatives (insurance) could be used in agriculture. In his study, a Cobb-Douglas production function was applied to actual yields and weather conditions in Ontario. His model evaluated yields based on the relationship between exogenous weather factors holding inputs constant. Results revealed that both heat and rainfall do have significant effects on the yields of some crops. Lower heat significantly reduced the yields of corn and soybean while excess rainfall reduced hay yields. His results also showed that the pricing and payoff probabilities must be location specific to minimize basis risk.

Dairy cows that are exposed to high ambient temperature and high humidity usually respond with reduced milk yield. Early Missouri work (Johnson et al.) showed that when temperatures, or combined temperatures and humidity, increased cows consumed less feed. In addition, they reported that milk yield declined as the rectal temperature increased, and with the same high temperature, cows exposed to low humidity performed better than those exposed to high humidity. So an index with combined effects of environmental stressors, such as environmental temperature, radiant energy, relative humidity and wind speed, may be more critical to dairy cows comfort and performance than any separate single measure such as the ambient temperature alone.

THI, which incorporates the effects of both temperature and relative humidity, is calculated as:

$$(1)\ THI = TD - (0.55 - 0.55 * RH) * (TD - 58)$$

where THI is the daily mean temperature humidity index; TD is the mean dry bulb temperature in degrees Fahrenheit, and RH is the daily mean relative humidity in decimals (NOAA). In many analyses, THI has proven to be negatively correlated with dairy cows' milk yield. Although many research trials report the impact of climatic events on same day milk yield, there are also results indicating that the effect of climatic factors prior to the current day may have an even greater impact on milk yield. For example, a study in South Carolina reported that the correlation coefficient between the summation of THI above 74 for the preceding 4 days and the milk yield was -0.42 (Linvill and Pardue). Another study showed that during certain periods the effect of 2-day lag mean THI had the greatest effect on milk yield in Tifton, Georgia (West, Mullinix and Bernard).

Data

There are 6 weather data sets used in this study. These are daily temperature and daily humidity for each of three areas: Tifton, Georgia; Macon, Georgia; and Tallahassee, Florida. The temperature and humidity data for Tifton are collected from automated weather stations operated by the University of Georgia College of Agricultural and Environmental Sciences. The temperature and humidity data for Tallahassee and Macon are collected from the NCDC. Daily data from May 31 to July 25 were utilized for this study. These data were available from 1992-2002 for Tifton, from 1949-2000 for Macon, and from 1948-2000 for Tallahassee.

West, Mullinix and Bernard fit a linear relationship between daily milk yield for Holstein cattle in Tifton, Georgia and the 2-day lag of daily THI as:

$$(2)\qquad Y = 29.15 - 0.88(x - \overline{X})$$

where Y is the daily milk yield in kg per head, $\overline{X}$ is the mean of the 2-day lag of the daily THI, and x is the 2-day lag of the daily THI. We use these regression results along with daily THI data for Tifton, Georgia to simulate 11 years' (1992-2002) of daily milk yield during the hot period between May 31 and July 25.

Methodology

The 56 day period from May 31-July 25 is divided into 4 sub-periods of 14 days each. Sub-period 1 is from May 31 to June 13. Sub-period 2 is from June 14 to June 27. Sub-period 3 is from June 28 to July 11 and sub-period 4 is from July 12 to July 25.

The following notation will facilitate the discussion.

▪ i represents the i^{th} year;

▪ k represents the k^{th} sub-period within each year, k=1,2,3,4;

▪ j represents the j^{th} day within each sub-period of each year, $j = 1, 2,\dots 14$;

▪ THI is calculated with a 2-day lag, thus THI_{ikj} represents THI measured two days previous to the j^{th} day in the k^{th} sub-period of the i^{th} year;

▪ $\overline{THI}_{ik}$ is the mean of the 2-day lagged daily THI for the k^{th} sub-period of the i^{th} year;

$$(3) \quad \overline{THI}_{ik} = \frac{1}{14}\Big(\sum_{j=1}^{14} THI_{ikj}\Big)$$

▪ $\overline{THI}_{k}$ is the mean of $\overline{THI}_{ik}$ for the k^{th} sub-period across different years;

$$(4) \quad \overline{THI}_{k} = \frac{1}{I}\Big(\sum_{i=1}^{I} \overline{THI}_{ik}\Big)$$

▪ $\overline{Yield}_{ik}$ is the mean of daily milk yield for the k^{th} sub-period of the i^{th} year;

$$(5) \quad \overline{Yield}_{ik} = \frac{1}{14}\Big(\sum_{j=1}^{14} Yield_{ikj}\Big)$$

▪ $\overline{Yield}_{k}$ is the mean of $\overline{Yield}_{ik}$ for the k^{th} period across different years;

$$(6)\quad \overline{Yield}_k = \frac{1}{I}(\sum_{i=1}^{I} \overline{Yield}_{ik})$$

Purchasers of THI insurance would select a strike which represents the level of THI where the insurance begins making indemnity payments. We assume an indemnity function similar to that used for GRP. Specifically, for each location, the indemnity paid in year *i* sub-period *k* is calculated as

$$(7)\qquad D_{ik} = \max\left(0, \frac{\overline{THI}_{ik} - strike}{strike}\right) \times protection \quad for\ each\ k = 1, 2, 3, 4.$$

where *D* is the indemnity and the subscripts are as previously indicated. Protection is a dollar amount that represents the maximum possible indemnity. Protection and strike are both chosen by the purchaser.

Since the insurance is designed to protect against levels of THI higher than the strike, the higher (lower) the strike, the lower (higher) the premium rate. For each location and sub-period, a break-even premium rate is calculated as:

$$(8)\qquad Premium\ rate_k = \frac{\sum_{i=1}^{I} \max\left(0, \frac{\overline{THI}_{ik} - strike}{strike}\right)}{I} \quad for\ each\ k = 1, 2, 3, 4.$$

The premium paid is simply the product of the premium rate and the protection

$$(9)\qquad Premium_k = Premium\ rate_k \times protection \quad for\ each\ k = 1, 2, 3, 4$$

We exam the extent to which THI insurance based on weather stations in Tallahassee and Macon reduce revenue variability for a representative dairy farmer in Tifton. For simplicity we assume that milk prices are non-stochastic and equal to one unit of currency per unit of milk. This allows us to define revenues solely in terms to milk production. We further assume that insurance premiums and indemnities are also denominated in kilograms of milk production. Revenue with no THI insurance contract is calculated as:

$$(10)\quad REV_{ik,w/o} = \sum_{j=1}^{14} Yield_{ikj} = \overline{Yield_{ik}} * 14.$$

Revenue with a THI insurance contract is calculated as:

$$(11)\quad REV_{ik,w} = \left(\overline{Yield_{ik}} * 14\right) - \left(PR_k \times protection\right) + D_{ik}\,.$$

The percentage reduction in revenue variability due to having purchased a THI insurance contract is calculated as:

$$(12)\quad \theta_k = 1 - \frac{\mathrm{var}(REV_{ik,w})}{\mathrm{var}(REV_{ik,w/o})}.$$

Results

Figure 1 shows mean THI for each sub-period calculated over the period 1992-2000. In each sub-period the THI at the three locations have the same trend especially after 1995. The overall correlation (across four sub-periods) of THI is 0.88 between Tifton and Tallahassee and 0.77 between Tifton and Macon.

Table 1 contains break-even premium rates for THI insurance contracts based on Tallahassee. For a given strike, premium rates are higher in later sub-periods because the higher expected level of THI in later sub-periods renders higher expected indemnity payment. For a given sub-period, premium rates are higher for lower strikes since the lower the strike the more likely that the insurance contract will pay an indemnity. Table 2 shows similar results for Macon. For a given strike and sub-period, premium rates based on Tallahassee are always higher than those based on Macon. This, of course reflects the fact that Tallahassee is south of Macon and has higher average temperature and humidity. Thus if a dairy farmer in south Georgia chose to purchase a THI insurance contract based on Tallahassee rather than Macon, she/he would pay more in premium for a given strike and sub-period but also expect, over time, to receive more in indemnities. Premium rates of zero indicate that in the database there were no

THI observations in excess of the strike. Of course, in reality there is some probability that THI could exceed the strike even if such an event has not been recorded in the NCDC database. An insurance provider would likely fit an estimated density function to the NCDC data so that positive premium rates could be generated even for extreme strikes.

Assume a dairy farmer in Tifton has 250 head of dairy cows. Following the findings of West, Mullinix and Bernard we will further assume that the cows have an expected daily milk yield during this period of 29.15 kg per head. Again abstracting away from price, expected revenue is 7,288 kg of milk per day or 102,025 kg of milk over a 14-day sub-period. We assume that the farmer can purchase THI insurance for each sub-period based on either Tallahassee or Macon. Regardless of the strike chosen, we assume the farmer chooses a level of insurance protection equal to 102,025 kg of milk for each sub-period. Since the premium is set at a break-even level, a risk-averse farmer will want to purchase the insurance if it provides any reduction in revenue variability.

Based on the overlapping 9 years of weather data (from 1992 to 2000) for Tifton, Tallahassee and Macon, we can calculate the mean and variance of the farmer's realized revenue for different scenarios, with and without insurance. Table 3 shows for each two-week sub-period the daily mean revenue and the corresponding standard deviation, for different insurance scenarios. Though the premiums are set to be break-even over the entire time-series of weather data available for Tallahassee and Macon, they are not necessarily break-even over the 9-year subset of data being evaluated here. Thus, for Tallahassee mean revenues with insurance are always higher than mean revenues without insurance for the same sub-period. This reflects the fact that over this 9-year period Tallahassee THI measures between May 31 and July 25 tended to be higher than longer-term averages.

For each sub-period, the purchase of THI insurance consistently reduces revenue risk (measured in standard deviation) regardless of the strike level and regardless of whether the insurance is purchased on Tallahassee or Macon. For each sub-period and for any strike, the standard deviation of revenue with insurance based on Tallahassee is smaller than the standard deviation of revenue with insurance based on Macon.

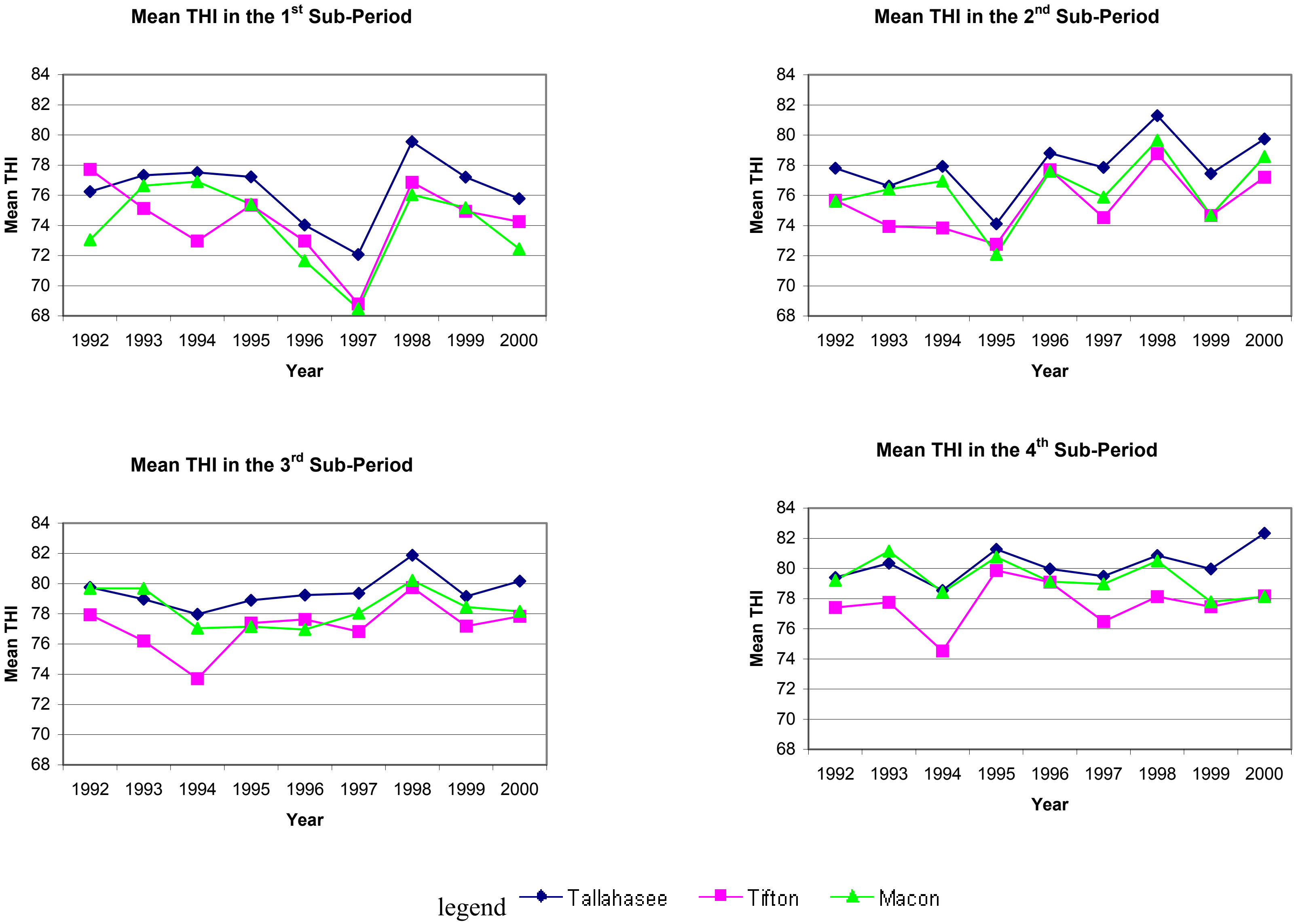
Table 4 presents the percentage reduction in revenue variance as a result of purchasing THI insurance based on either Tallahassee or Macon for various combinations of sub-periods and strikes. The insurance seems to reduce revenue variation most in the second two-week sub-period. The least reduction in revenue variation occurs in the fourth sub-period.

Discussion

Recent years have witnessed rapid development of weather derivatives. To date, most applications are centered on nonagricultural industries. However, agricultural applications of weather derivatives (insurance) are being widely discussed. In this paper, we propose a unique THI insurance instrument with potential applications to dairy production.

Our results suggest that THI insurance could provide risk management benefits to south Georgia dairy producers. Further research may evaluate the potential for fitting density functions to the historical THI data. Doing so would allow an insurer to generate positive break-even premium rates for extreme levels of strike. A further extension would abandon the assumption of break-even premium rates. The insurance provider would be assumed to add loads, such as reserve load, catastrophic load, and administration cost and return on equity to the underlying break-even premium rate. Since the premium could no longer be assumed to be break-even over the long-term, the efficacy of the insurance instrument would need to be evaluated using an expected utility framework.

Figure 1: Mean THI for Each Sub-Period Based on Data for May 31 - July 25, 1992-2000



Mean THI in the 1st Sub-Period

Mean THI in the 2nd Sub-Period

Mean THI in the 3rd Sub-Period

Mean THI in the 4th Sub-Period

Table 1: Premium Rates at Different Strikes for THI Insurance Based on Tallahassee

THI	Breakeven premium rate (%)			
Strike	Period 1	Period 2	Period 3	Period 4
74	2.58056	5.12591	6.30404	7.14680
75	1.21282	3.72423	4.88665	5.71817
76	0	2.35944	3.50657	4.32714
77	0	1.03009	2.16232	2.97225

Table 2: Premium Rates at Different Strikes for THI Insurance Based on Macon

THI	Breakeven premium rate (%)			
Strike	Period 1	Period 2	Period 3	Period 4
73	2.01772	5.01498	6.50983	7.96680
74	0.63910	3.59586	5.07051	6.50779
75	0	2.21458	3.66957	5.08768
76	0	0.86965	2.30550	3.70495
77	0	0	0.97685	2.35813

Table 3: Mean Revenue and the Standard Deviation of Revenue

Strike at 74 (Tallahassee)

week	mean	meanin	std	stdin
1-2	7707.69	7748.42	573.464	429.080
3-4	7460.65	7476.39	445.759	283.408
5-6	7084.73	7165.71	355.339	266.051
7-8	6976.01	7069.55	337.079	270.271

Strike at 74 (Macon)

week	mean	meanin	std	stdin
1-2	7707.69	7658.85	573.464	457.313
3-4	7460.65	7433.22	445.759	292.608
5-6	7084.73	7146.05	355.339	312.056
7-8	6976.01	7027.44	337.079	303.374

Strike at 75 (Tallahassee)

week	mean	meanin	std	stdwzin
1-2	7707.69	7747.87	573.464	430.618
3-4	7460.65	7476.18	445.759	285.293
5-6	7084.73	7164.63	355.339	267.159
7-8	6976.01	7068.30	337.079	270.973

Strike at 75 (Macon)

week	mean	meanin	std	stdin
1-2				
3-4	7460.65	7433.58	445.759	294.104
5-6	7084.73	7145.23	355.339	312.361
7-8	6976.01	7026.75	337.079	303.545

Strike at 76 (Tallahassee)

week	mean	meanin	std	stdwzin
1-2				
3-4	7460.65	7475.97	445.759	287.139
5-6	7084.73	7163.57	355.339	268.240
7-8	6976.01	7067.09	337.079	271.661

Strike at 76 (Macon)

week	mean	meanin	std	stdin
1-2				
3-4	7460.65	7433.94	445.759	295.582
5-6	7084.73	7144.44	355.339	312.665
7-8	6976.01	7026.09	337.079	303.720

Strike at 77(Tallahassee)

week	mean	meanin	std	stdin
1-2				
3-4	7460.65	7475.78	445.759	288.947
5-6	7084.73	7162.55	355.339	269.297
7-8	6976.01	7065.90	337.079	272.338

Strike at 77 (Macon)

week	mean	meanin	std	stdin
1-2				
3-4				
5-6	7084.73	7143.66	355.339	312.969
7-8	6976.01	7025.44	337.079	303.897

mean represents the daily mean revenue without insurance during each period at each strike;

meanin represents the daily mean revenue with insurance during each period at each strike;

s*td* represents the standard deviation without insurance during each period at each strike;

stdin represents the standard deviation with insurance during each period at each strike.

Table 4: Revenue Variance Reduction

Strike level	Period	Tallahassee	Macon
Strike 74	Period 1	44.02%	36.41%
	Period 2	59.58%	56.91%
	Period 3	43.94%	22.88%
	Period 4	35.71%	19.00%
Strike 75	Period 1	43.61%	
	Period 2	59.04%	56.47%
	Period 3	43.47%	22.73%
	Period 4	35.38%	18.91%
Strike 76	Period 1		
	Period 2	58.51%	56.03%
	Period 3	43.01%	22.58%
	Period 4	35.05%	18.81%
Strike 77	Period 1		
	Period 2	57.98%	
	Period 3	42.56%	22.43%
	Period 4	34.72%	18.72%

References

Forrest, P., J. “A Case Study of Heating Oil Partner’s Weather Hedging Experience.” *Risk Books, Climate Risk and the Weather Market*, p266.

Johnson, H.D., A.C. Ragsdale, I. L. Berry, and M.D. Shanklin. “Temperature-Humidity Effects Including Influence of Acclimation in Feed and Water Consumption of Holstein Cattle.”
University of Missouri Agric. Exp. Sta. Rsch. Bull. 846(1963). Columbia.

Linvill, D.E., and F.E. Pardue. “Heat Stress and Milk Production in the South Carolina Coastal Plains.” *Journal of Dairy Science*. 75(1992):2598-2604.

National Oceanic and Atmospheric Administration. “Livestock Hot Weather Stress.” *US Dept. Commerce, Natl. Whether Serv Central Reg., Reg. Operations Manual Lett*. (1976) C-31-76.

Martin, S., W., B., J., Barnett, K., H., Coble, “Developing and Pricing Precipitation Insurance.” *Journal of Agricultural and Resource Economics*, 26(1):261-274.

Turvey C. G. “ Weather Derivatives for Specific Event Risks in Agriculture.” *Review of Agricultural Economics* 23(2001):333-352.

West J.W., B.G. Mullinix, and J.K.Bernard “Effects of Hot, Humid Weather on Milk Temperature, Dry Matter Intake, and Milk Yield of Lactation Dairy Cows.” *Journal of Dairy Science*. 86(2003):232-242.