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The Potential Effects of Climate Change on the Productivity of U.S. Dairies

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Poster prepared for presentation at the Agricultural & Applied Economics Association's 2012 AAEA Annual Meeting, Seattle, WA, August 12-14, 2012.

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Background

Global warming is likely to increase temperature levels and the frequency of extreme weather events, including hotter daily maximums and more frequent or longer heat waves, which could adversely affect livestock production in the warm season (Hatfield, et al. 2008). Increased thermal stress can reduce meat and milk production and lower reproduction rates (Fuquay, 1981; Morrison 1983; St-Pierre, Cobanov and Schnitkey, 2003). Methods that livestock producers use to mitigate thermal stress – including modifications to animal management or housing – tend to increase production costs and reduce productivity.

A limited number of studies have used agricultural engineering models of the relationship between climatic conditions and feed intake to estimate the effects of climate on the performance of domestic livestock (Frank et al, 2001; St-Pierre, Cobanov and Schnitkey, 2003). However, producer behavior may diverge from engineering models in practice.

Method

- Using a national survey of dairy producers, we estimate the relationship between the local climate and technical efficiency using a stochastic production frontier model.
    - Allows us to examine how farmers actually adapt to diverse climate in the U.S.
- Based on forecasts from four climate change models and our model estimates, simulate the economic costs of climate change for dairy producers in 2030.

Data

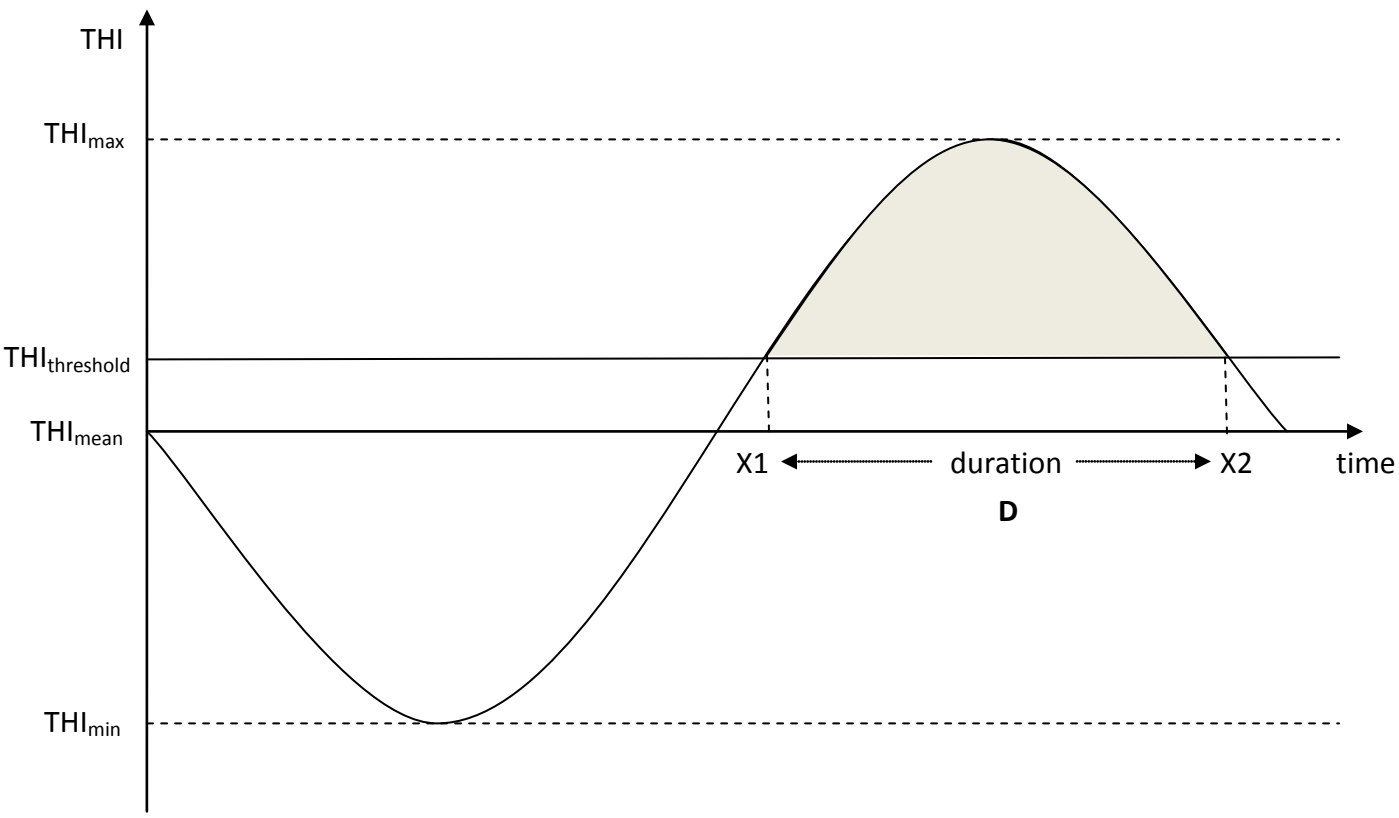
Climate data

- Use the Parameter-elevation Regressions on Independent Slopes Model (PRISM), developed at Oregon State University.
- PRISM generates climate estimates for each 4km grid cell in the U.S.

Generating THI Load

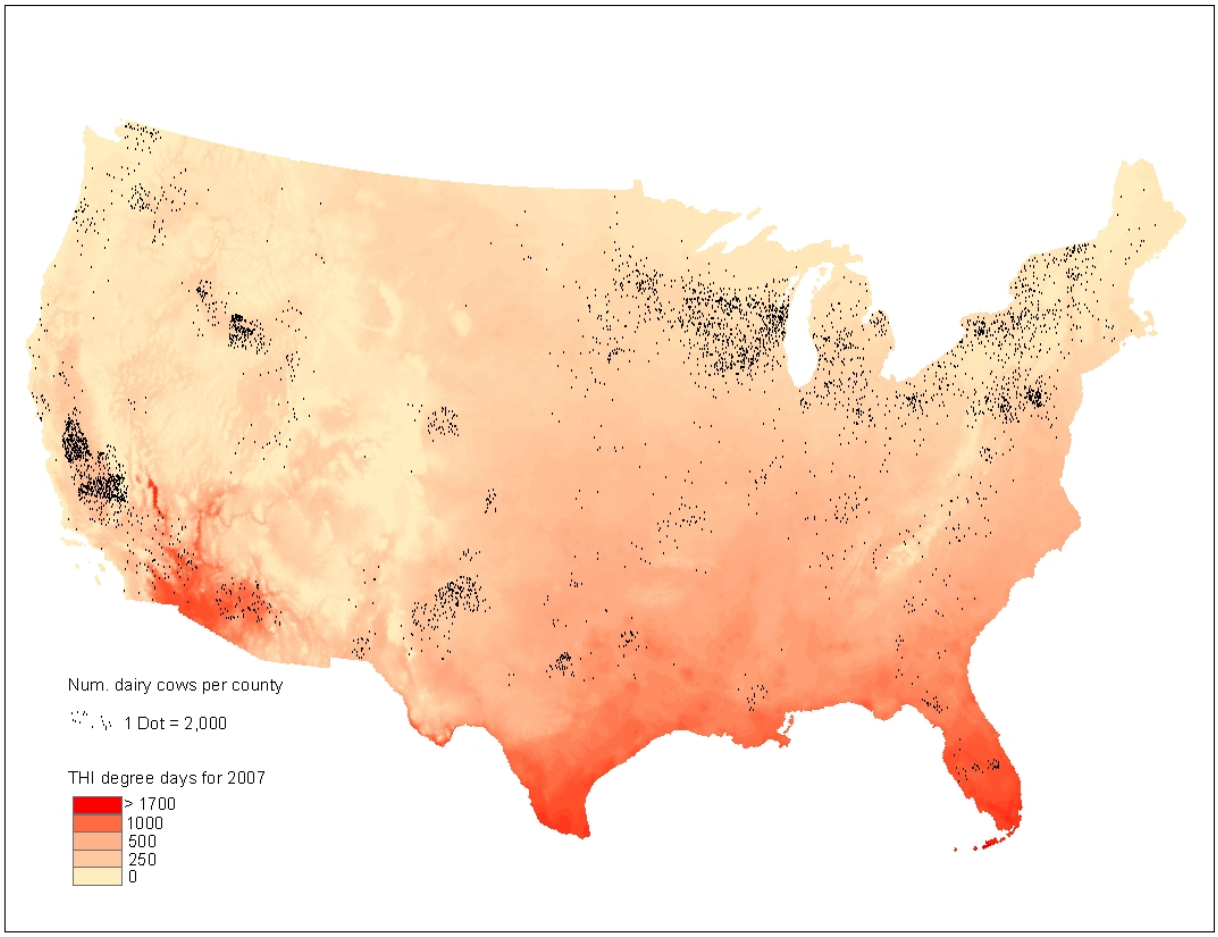
- Animal scientists use the temperature humidity index (THI) to estimate the effect of heat stress on livestock productivity.
- Generally, dairy cows experience heat stress when the THI is above 72.
- THI load is similar to "cooling degree days" with an adjustment for humidity
- THI load = the "average" amount that the THI is above the THI threshold * days above THI threshold

Figure 1. Thermal Humidity Index Load for One Day



We calculate the THI load for each 4-km pixel in the U.S. Comparing this with the location of dairy cows in the entire U.S., we see that dairy production occurs in a variety of THI loads:

Figure 2. Relationship of Temperature Humidity Index Load to Location of Dairy Cows, U.S. 2007



Data Sources: U.S. Census of Agriculture, 2007 and PRISM.

Dairy operation data

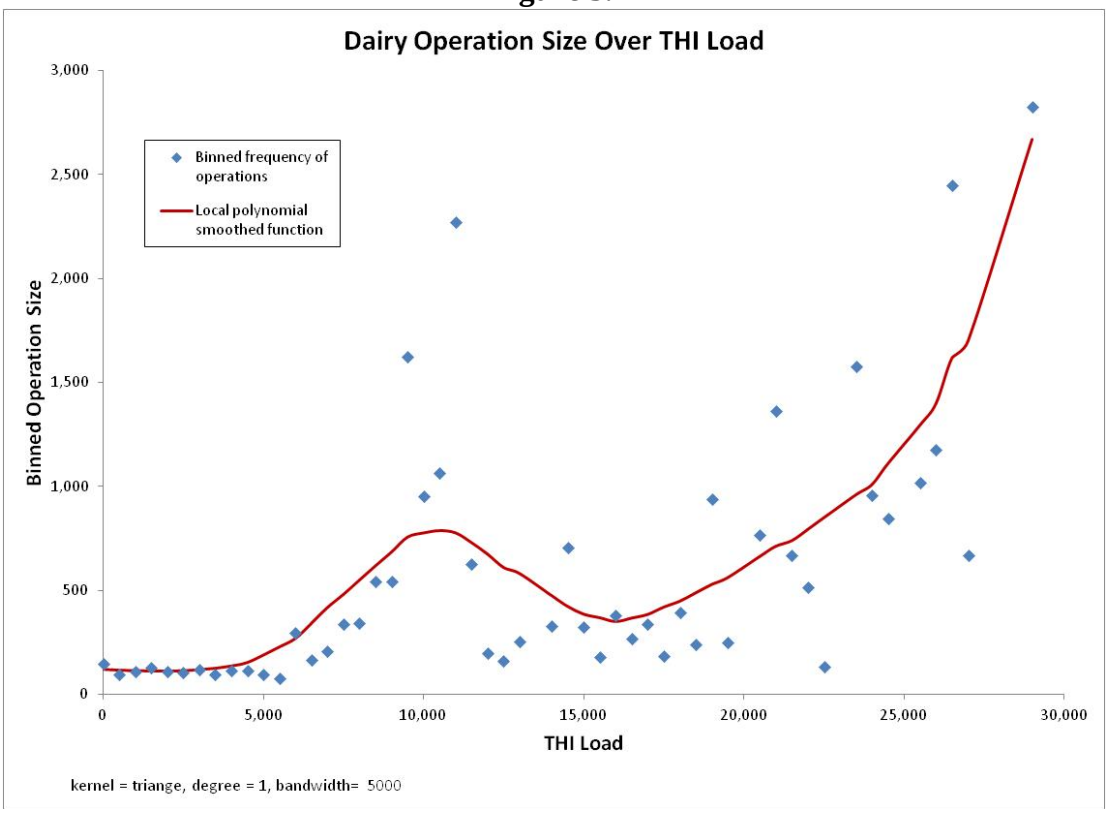
- Dairy operation data used in the frontier analysis are drawn from the USDA's Agricultural Resource Management Survey (ARMS) collected in 2005 and 2010.
- ARMS survey targeted dairy operations in 24 States.

Matching Dairy Data to THI Load Data:

- Find the latitude and longitude of the centroid of the zip code of each operation in ARMS.
- Use mapping software to find the grid cell of this latitude-longitude point. This grid cell is used as the location for the climate data of each operation.

Summary statistics show that dairy operation size is positively correlated with THI load, suggesting that operation size may confound relationships between THI load and productivity:

Figure 3.


Dairy Operation Size Over THI Load
Binned frequency of operations
Local polynomial smoothed function
Binned Operation Size
3,000
2,500
2,000
1,500
1,000
500
0
0
5,000
10,000
15,000
20,000
25,000
30,000
THI Load
kernel = triange, degree = 1, bandwidth= 5000

We therefore examine means according to operation size class and THI load.

- Operations in areas with highest THI loads produce significantly less milk per cow than operations in the lower THI loads, for all three size categories.
- Farms in warmer regions have higher energy expenditures per unit.
- For medium and large operations, unit costs are about 10 percent higher on average in the warmest regions compared to the coolest region.
- However, for the medium and large operations, the net returns per unit are not statistically significantly different.
- This suggests that higher product prices in the warmer THI regions offset the somewhat higher production costs.

Table. 1. Dairy Productivity by THI load and Dairy Size, 2010

	THI load		
Dairy size	Low	Medium	High
Small			
THI load	1,976	5,272***	13,586***
Milk production (cwt.)	7,693	8,206*	7,564
Milk production per cow (cwt./head)	158	169**	133***
Energy expenditures per unit ($/cwt.)	1.069	0.912**	1.270**
Total costs per unit ($/cwt.)	37.82	33.28***	38.72
Net returns per unit ($/cwt.)	-18.91	-14.36***	-19.69
Observations	190	174	134
Medium			
THI load	2,275	5,036***	16,727***
Milk production (cwt.)	24,993	25,544	24,708
Milk production per cow (cwt./head)	206	211	159***
Energy expenditures per unit ($/cwt.)	0.838	0.773	0.933*
Total costs per unit ($/cwt.)	24.16	23.52	26.10**
Net returns per unit ($/cwt.)	-6.36	-4.85**	-7.39
Observations	156	129	114
Large			
THI load	2,002	5,813***	20,879***
Milk production (cwt.)	153,229	174,226	170,730
Milk production per cow (cwt./head)	228	227	187***
Energy expenditures per unit ($/cwt.)	0.654	0.662	0.881***
Total costs per unit ($/cwt.)	19.66	20.18	21.48**
Net returns per unit ($/cwt.)	-1.71	-2.76*	-2.14
Observations	95	74	57

Notes: Dairy size categories defined as: small (cwt. milk $<$ 15,000), medium (15,000 $<$ Cwt. $\leq$ 50,000), Large (50,000 $<$ Cwt.). THI load categories defined as: low (THI $<$ 3,500); medium (3,500 $<$ THI $\leq$ 10,000) and high (10,000 $<$ THI). Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels for a t-test of a difference in means with the "low" THI category.

Results

Estimation of the stochastic production frontier model indicates that THI load is positively and statistically significantly related to inefficiency.

Simulations

To simulate effects of climate change to 2030 we do the following:

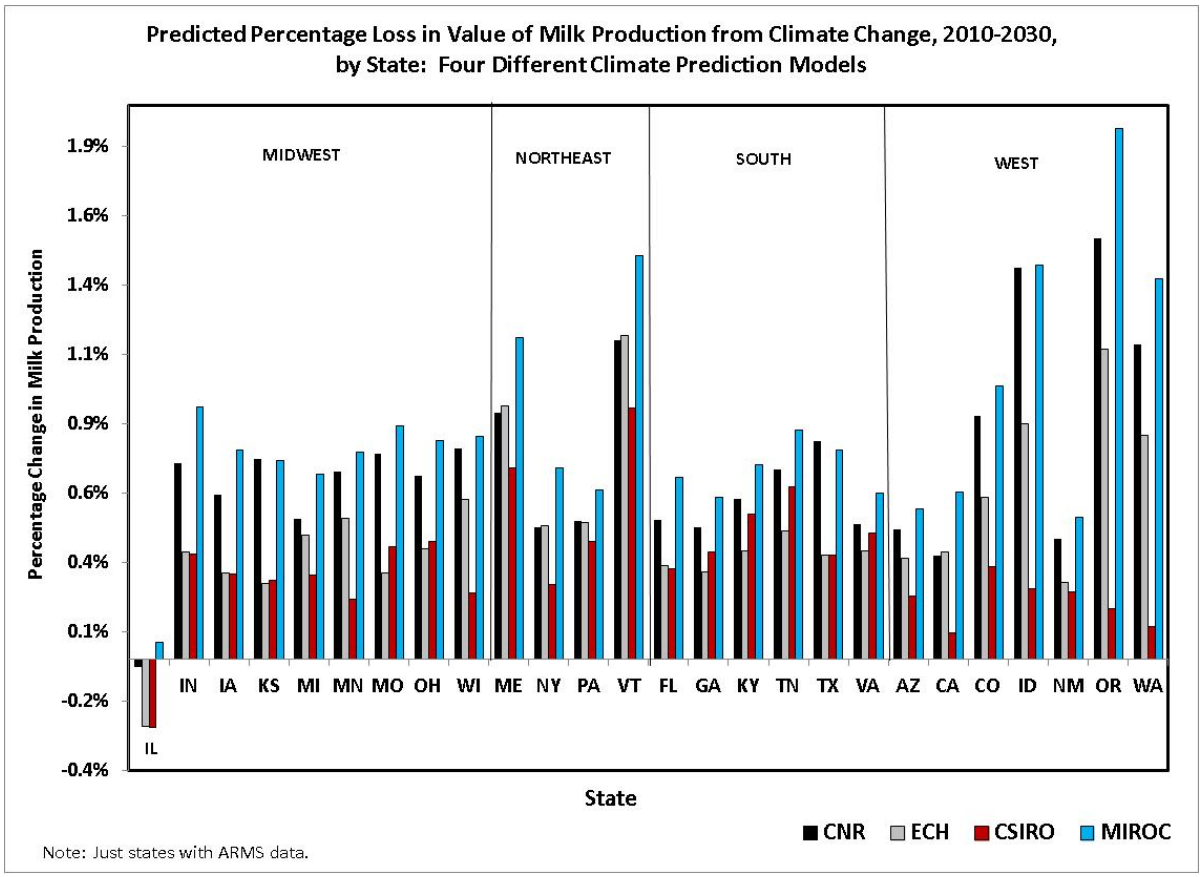
- Generate predictions of the THI load in 2030 under four climate models.
- Use these THI predictions to estimate dairy production efficiency in 2030.
- Calculate the percentage change in efficiency resulting from the forecast climate change between 2010 and 2030.
- Multiply this percentage change in efficiency by current milk revenue to predict the change in the value of milk production attributable to climate change.
- Assumes no change in inputs, no milk price change, no technical change, and no geographic shifts.

Table 2: Changes in Value of Milk Production Due to Changes in Climate Between 2010 and 2030: Four Climate Models

	Climate Model			
	CNR	**ECH**	**CSIRO**	**MIROC**
By Farm				
% Change				
Mean	-0.81%	-0.63%	-0.41%	-0.95%
Standard Deviation	6.04%	5.66%	4.86%	6.59%
Minimum	-9.86%	-7.05%	-3.72%	-9.56%
Maximum	13.78%	13.78%	13.78%	13.78%
Change (in $)				
Mean	-$3,022	-$2,327	-$1,335	-$3,637
Standard Deviation	$74,856	$56,638	$41,799	$80,779
Minimum	-$663,349	-$383,536	-$107,985	-$669,383
Maximum	$183,958	$183,958	$183,958	$183,958
Total				
Change (in $)	-$120,129,611	-$92,521,952	-$53,069,264	-$144,603,622

Notes: Value of milk production estimated at current (2010 prices). CNR (Centre National de Recherches Météorologiques, France); CSIRO (Commonwealth Scientific and Industrial Research Organisation, Atmospheric Research, Australia); ECH (Max Planck Institute for Meteorology, Germany); MIROC (Center for Climate System Research, University of Tokyo; National Institute for Environmental Studies, and Frontier Research Center for Global Change, Japan).

Figure 3.


Predicted Percentage Loss in Value of Milk Production from Climate Change, 2010-2030,
by State: Four Different Climate Prediction Models
MIDWEST
NORTHEAST
SOUTH
WEST
Percentage Change in Milk Production
1.9%
1.6%
1.4%
1.1%
0.9%
0.6%
0.4%
0.1%
-0.2%
-0.4%
IL
IN IA KS MI MN MO OH WI ME NY PA VT FL GA KY TN TX VA AZ CA CO ID NM OR WA
State
CNR
ECH
CSIRO
MIROC
Note: Just states with ARMS data.

Conclusions

- THI load is positively and statistically significantly related to inefficiency.
- The average farm sees less than a 1% decline in the value of milk production due to climate change between 2010 and 2030.
- At worst, some farms see a 10% decline, while at best some farms see a 14% increase.
- Regional effects are difficult to discern from the climate models.

References

Hatfield, J., K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, and D. Wolfe. (2008) Agriculture. In: *The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC., USA, 362 pp

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Morrison, S. R. (1983) "Ruminant heat stress: effect on production and means of alleviation." *Journal of Animal Science*. 57:1594–1600.

St. Pierre, N.R., B. Cobanov, and G. Schnitkey (2003) "Economic Loss from Heat Stress by US Livestock Industries." *Journal of Dairy Science*. 86(E Suppl.):E52-E77.