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

James M. MacDonald
Economic Research Service
U.S. Department of Agriculture

National Workshop for Dairy Economists and Policy Analysts
Milwaukee, WI
May 1, 2014

The views expressed herein are the author's and do not necessarily reflect official policy of ERS or USDA

Global Warming & Dairy Production

- ↑ daily temperatures and ↑ frequency of heat waves are likely to ↓ milk and meat production in animals
- Producers adapt to mitigate heat stress, and adaptations ↑ production costs
  - Cooling, via fans, water, & housing design
  - Feed formulations, breeding
- What can we say about the likely impact?

Current U.S. Dairy Production Covers a Wide Range of Climates...

Dairy in the Sonoran Desert in Arizona

(Arizona is 12th-ranked dairy state)

USDA United States Department of Agriculture, Economic Research Service

...So the First Step is to Evaluate How Cross-Section Climate Variation Affects Dairy Productivity

Dairy in Vermont's Champlain Valley

(Vermont is 19th-ranked dairy state)

USDA United States Department of Agriculture, Economic Research Service

The Approach

- Sneeringer and Key (ERS) combined farm-level operations data with finely-scaled climate data...
- ...to estimate how the local thermal environment affects technical efficiency in US dairies (annual, in the cross section)
- Used results to estimate potential costs to dairy sector in 2030 arising from ↑ heat stress

USDA United States Department of Agriculture, Economic Research Service

Using Cross Section Differences to Evaluate Possible Temporal Impact

- Strengths: lots of accurate data in the cross-section data, and a wide range of heat stress
  - So we can identify current impacts of heat stress
  - Within an effective model of production
- What's left out?
  - Adaptation via geographic shifts
  - Adaptation via new technology, new breeding
  - Indirect impacts of climate change, on crops & bugs

USDA United States Department of Agriculture, Economic Research Service

Data Sources

- Climate data from PRISM at Oregon State
  - Model extrapolates between weather stations to estimate weather data for 4km grid cells across US
  - Used data from 2005 and 2010
  - Match to lat/long of centroid of postal zip code associated with the farm
  - Where do the farms come from?

USDA United States Department of Agriculture, Economic Research Service

ARMS Data

- Agricultural Resource Management Survey
  - Annual representative survey of US farms
  - Primary source of farm finance data for USDA
- Specialized dairy versions in 2005, 2010
  - Representative of dairy farms in 24 Major States
    - 1,236 farms in 2005; 1,123 in 2010
    - Production & inputs
    - Revenue & expenses (detail)
    - Production practices & technology
    - Location identifiers: state, county, zip code

USDA United States Department of Agriculture, Economic Research Service

Measuring Heat Stress: the THI Load

THI is Temperature-Humidity Index;

$$THI = (\text{dry bulb temperature } °C) + (0.36 \times \text{dew point temperature } °C) + 41.2$$

Animals experience heat stress above a THI threshold, set at 70 and at 65 in this study.

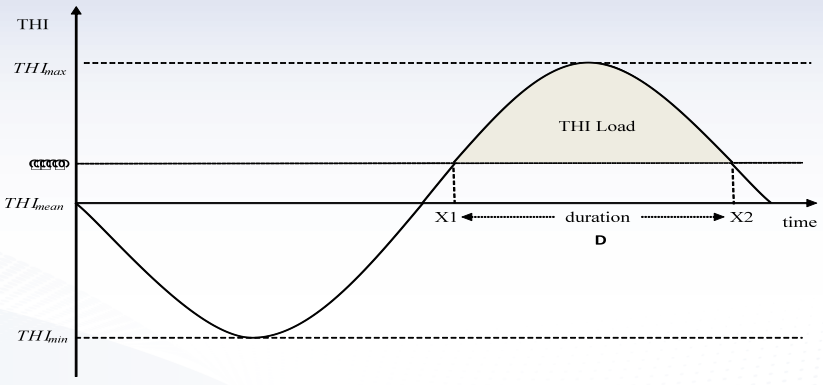
THI Load measures extent and duration of period above threshold

The paper models monthly THI load with average monthly min and max temperature, average dew point, and sine curve for movement between min and max

USDA United States Department of Agriculture, Economic Research Service

This is for a day; the paper then aggregates to monthly and annual

Figure A1. Temperature Humidity Index Load for One Day

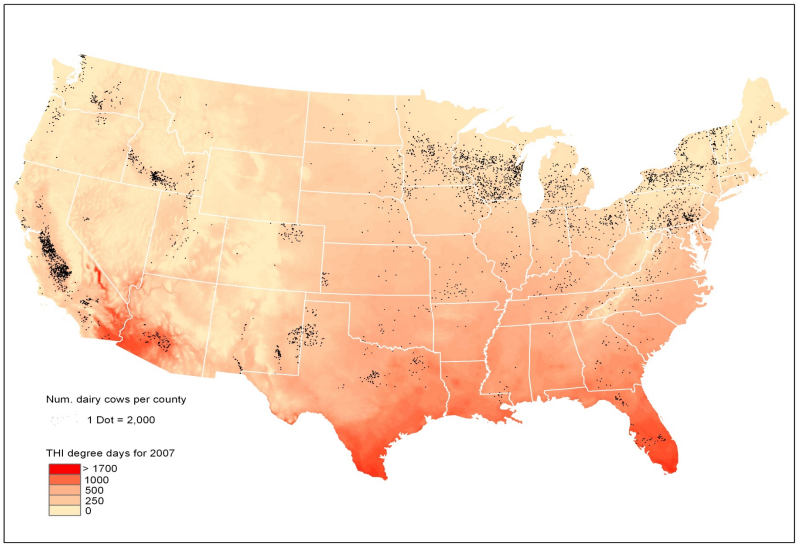


Note: The THI is assumed to follow a sine curve throughout the day. The THI load is the area under the sine curve and above the THI threshold ( ).

USDA United States Department of Agriculture, Economic Research Service

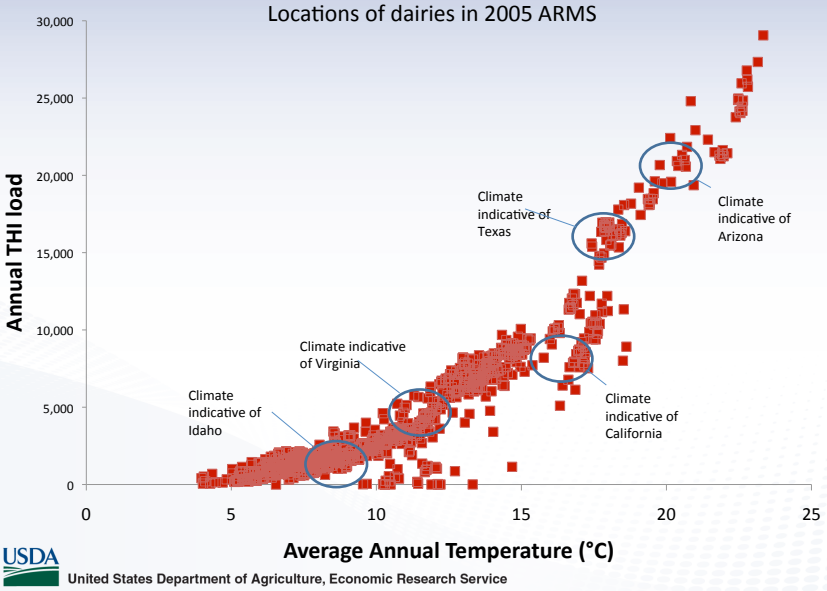
(THI) Load and the Location Of U.S. Dairy Cows

Substantial Cross-Section Variation



Relationship between temperature and THI load

Locations of dairies in 2005 ARMS



USDA United States Department of Agriculture, Economic Research Service

Table 2: Dairy Productivity by THI Load and Dairy Size, 2010

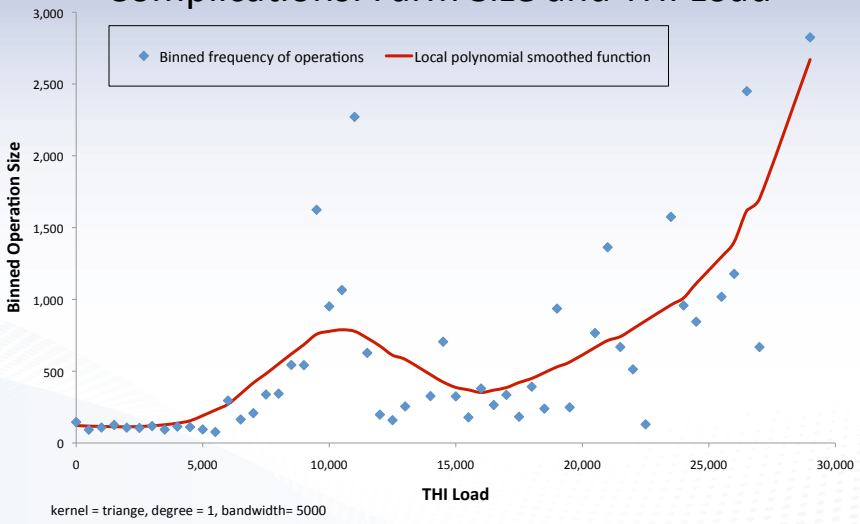
Dairy size	THI load		
	< 3,500	3,500 – 10,000	> 9,999
Small (*cwt.* < 15,000)			
THI load	2,669	6,696***	18,134***
Milk production per cow (cwt./head)	160	161	117***
Energy expenditures per unit ($/cwt.)	1.027	1.021	1.464**
Milk cow mortality rate	0.058	0.059	0.063
Total costs per unit ($/cwt.)	37.27	34.35*	39.10
Medium (15,000 ≤ *cwt.* < 50,000)			
THI load	2,894	6,324***	18,478***
Milk production per cow (cwt./head)	207	204	147***
Energy expenditures per unit ($/cwt.)	0.812	0831	0.963**
Milk cow mortality rate	0.061	0.067	0.055
Total costs per unit ($/cwt.)	24.27	23.47	26.49**
Large (50,000 ≤ *cwt.*)			
THI load	2,748	7,879***	19,348***
Milk production per cow (cwt./head)	228	226	185***
Energy expenditures per unit ($/cwt.)	0.658	0.670	0.858***
Milk cow mortality rate	0.067	0.067	0.075
Total costs per unit ($/cwt.)	20.06	19.71	24.13**

Note: Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels for a t-test of a difference in means with the "low" THI category. THI load is measured in humidity adjusted degree hours. Farm size is measured in hundredweight of milk produced.

Source: NASS/ERS, Agricultural Resource Management Survey, 2010, version 4

USDA United States Department of Agriculture, Economic Research Service

Complications: Farm Size and THI Load

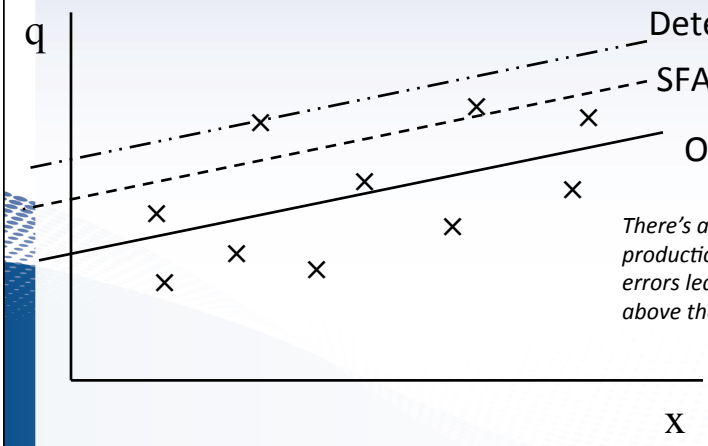


kernel = triange, degree = 1, bandwidth= 5000

Need to control for other factors affecting productivity

USDA United States Department of Agriculture, Economic Research Service

The Paper Models Production Using Stochastic Frontier Analysis (SFA)

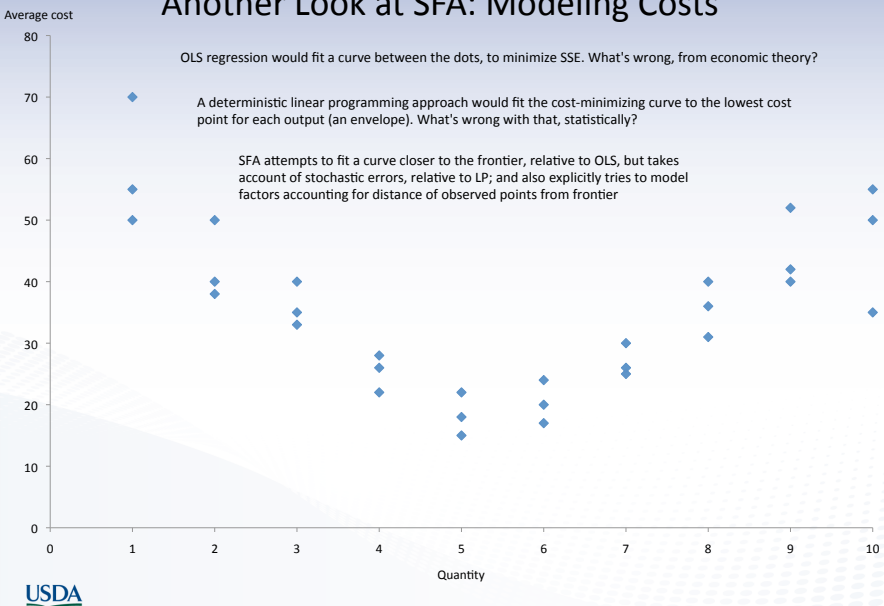


There's a frontier to production, and stochastic errors leave some firms above the frontier

Heat Stress Causes Production to Fall Below the Frontier

USDA United States Department of Agriculture, Economic Research Service

Another Look at SFA: Modeling Costs



OLS regression would fit a curve between the dots, to minimize SSE. What's wrong, from economic theory?

A deterministic linear programming approach would fit the cost-minimizing curve to the lowest cost point for each output (an envelope). What's wrong with that, statistically?

SFA attempts to fit a curve closer to the frontier, relative to OLS, but takes account of stochastic errors, relative to LP; and also explicitly tries to model factors accounting for distance of observed points from frontier

USDA United States Department of Agriculture, Economic Research Service

The Model

$$\ln q_i = f(x_i, \beta) + v_i - u_i,$$

q= milk produced (cwt)
X1=milk cows
X2=feed
X3=labor
X4=capital
X5=other inputs

Production is a translog functional form, with squared and interaction terms among inputs

u_i (the systematic part of the error) include operator age, education, experience (years producing milk), farm diversification (share of milk in sales), and THI load

Key results: q is lower, given inputs x, where THI load is higher.

USDA United States Department of Agriculture, Economic Research Service

Effects of THI Load

- Negative, statistically significant
  - ↑ in THI load of 1,000 degree hours associated with 3.7% ↓ in milk production
  - ↑ in *expected* THI load of 1,000 degree hours associated with 0.38% ↓ in milk production
  - Expected (climate?) vs. unexpected (weather?)
- Aggregate impact of current heat stress:
  - At mean 2010 dairy, heat stress reduces production by 6%, from zero THI load

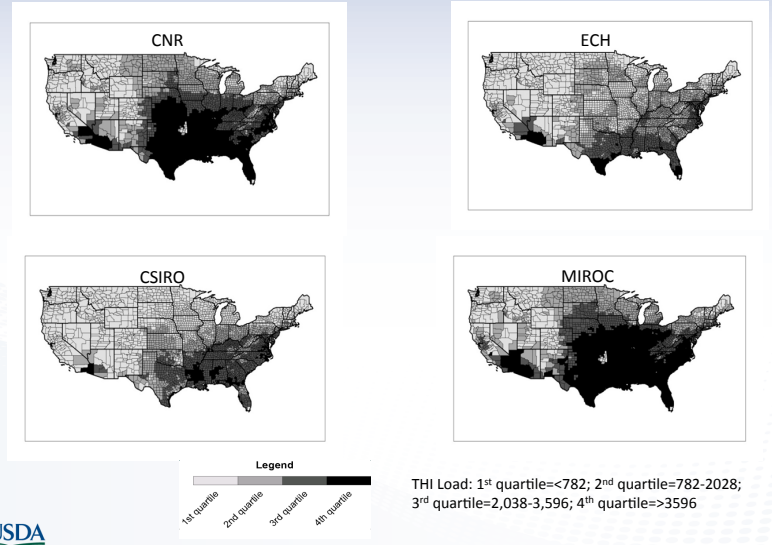
USDA United States Department of Agriculture, Economic Research Service

Next Step: Simulating Climate Change Impacts to 2030

- Uses four climate models to generate 2030 THI load predictions for each sample dairy
- Insert in model, generate predicted percentage change in efficiency
  - That is, no changes in inputs, technology, location, or relative prices from 2010
- Estimated aggregate production loss of 0.6-1.4%
  - For given amount of inputs

USDA United States Department of Agriculture, Economic Research Service

Climate Model Estimates of THI Change Differ Substantially



THI Load: 1st quartile=<782; 2nd quartile=782-2028; 3rd quartile=2,038-3,596; 4th quartile=>3596

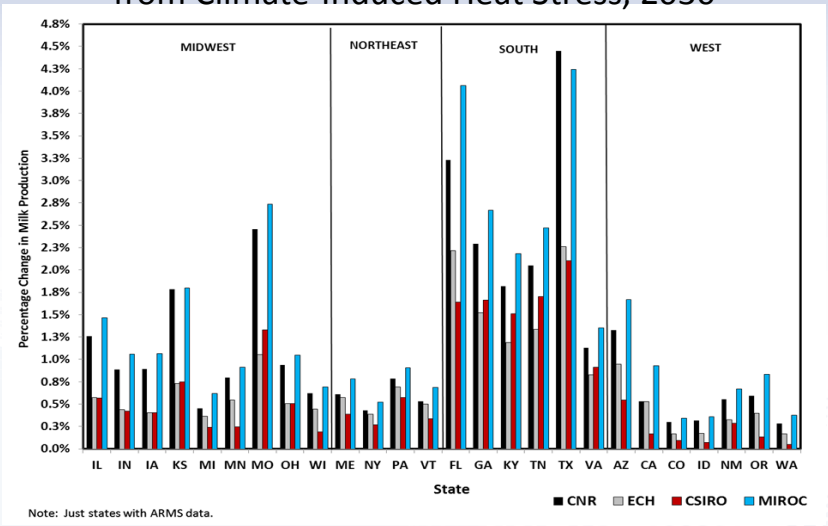
USDA United States Department of Agriculture, Economic Research Service

Changes in Milk Production Due to Changes in Climate, 2010-2030: Four Climate Models

	Climate Model			
	CNR	ECH	CSIRO	MIROC
Change in milk quantity		-Percent Change-		
Mean	-1.181	-0.80	-0.60	-1.35
Standard Deviation	6.98	4.17	3.98	7.43
Minimum	-18.07	-9.45	-9.16	-17.25
Maximum	2.89	2.89	2.89	2.89
Change in $ value of milk produced		-Millions of $-		
No market response	-165.5	-113.5	-79.3	-198.6
Hi demand elasticity	-96.2	-65.6	-45.7	-115.8
Low demand elasticity	-67.6	-46.0	-32.0	-81.4

USDA United States Department of Agriculture, Economic Research Service

Predicted Annual Reduction in Milk Production from Climate-Induced Heat Stress, 2030



Note: Just states with ARMS data.

USDA United States Department of Agriculture, Economic Research Service

Conclusions

- Modest production impacts in 20 year horizon
  - Substantially larger in South
- Geographic adjustment has small effects
- Limited focus—heat stress and production
  - But provides a model to think about *how* heat stress affects production,
  - And to help think about other channels of impact, via feed costs and pest/pathogen impacts...
  - And to help think about channels of adaptation, via equipment, feed formulation, breeding

USDA United States Department of Agriculture, Economic Research Service

Contacts

- Paper: "Potential Effects of Climate Change on the Productivity of U.S. Dairies" *American Journal of Agricultural Economics,* July 2014
  - Nigel Key (author)
    - nkey@ers.usda.gov
  - Stacy Sneeringer (author)
    - ssneeringer@ers.usda.gov
- James MacDonald (presenter)
  - macdonal@ers.usda.gov

USDA United States Department of Agriculture, Economic Research Service